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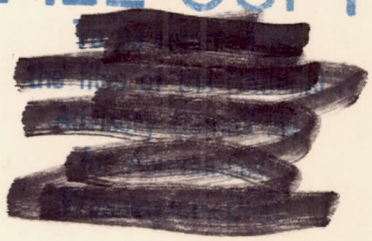
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HIGH TEMPERATURE CHARACTERISTICS OF 17 ALLOYS AT 1200° AND 1350° F

By J. W. Freeman, F. B. Rote, and A. E. White
University of Michigan

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TABLE OF CONTENTS

	Page
SUMMARY	1
INTRODUCTION	2
TEST MATERIALS	3
TEST PROCEDURE	4
RESULTS	6
DISCUSSION OF RESULTS	8
Analysis of Data	9
Theoretical Interpretation of Results	11
REFERENCES	13
DATA	
16-25-6 (Timken Alloy)	
Annealed	14
Hot Worked	17
Cold Worked	20
19-9W-Mo	23
19-9W-MoM (19-9 DL)	26
234-A-5	29
Gamma Columbium	
Annealed	32
Hot Rolled	35
Hot Worked	38
Cold Worked	41
N153	
Annealed	44
Hot Worked	47
Cold Worked	50
N154	
Annealed	53
Hot Worked	56
Cold Worked	59
N155	
Annealed	62
Hot Worked	65
Cold Worked	68
N156	
Annealed	71
Hot Worked	74
Cold Worked	77
Low Carbon N153	80
Low Carbon N154	83
Low Carbon N155	86
Age-Hardenable Inconel	89
Cast Vitallium	
Aged at 1350° F	92
Aged at 1500° F	95
Cast 422-19 alloy	98
Cast 61 alloy	101
Cast 6059 alloy	104
SUMMARIZED COMPARISON OF SEVENTEEN ALLOYS	107

NACA ACR No. 4C22

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

ADVANCE CONFIDENTIAL REPORT

HIGH-TEMPERATURE CHARACTERISTICS OF 17 ALLOYS AT 1200° AND 1350° F

By J. W. Freeman, F. B. Rote, and A. E. White

SUMMARY

This report presents the results of a study of the rupture-test characteristics of 13 wrought and 4 cast alloys which were considered to have promise for service in exhaust gas turbines.

The alloys studied were as follows:

16-25-6 (Timken Alloy)	Low Carbon N153
19-9W-Mo	Low Carbon N154
19-9W-MoM (19-9 DL)	Low Carbon N155
234-A-5	Age-Hardenable Inconel
Gamma Columbium	
N153	Cast Vitallium
N154	Cast 422-19 alloy
N155	Cast 61 alloy
N156	Cast 6059 alloy

Several of these materials were tested in more than one condition so as to introduce the effect of variations due to fabrication and heat treatment. For the wrought alloys, in addition to the rupture characteristics at 1350° F obtained from this research, the room-temperature tensile and the rupture-test characteristics at 1200° F have also been included as they were available from previous research.

At 1350° F the wrought alloys gave 100-hour rupture strengths which varied from 22,500 to 36,000 pounds per square inch. The 1000-hour strengths ranged from 12,500 to 27,500 pounds. Corresponding values for the cast alloys varied from 32,000 to 47,000 pounds for the 100-hour strength and from 25,000 to 36,000 pounds for the 1000-hour strength.

From the results of this investigation it becomes increasingly evident that, in the application and use of the test data, it is of great importance to note that wide ranges in properties are possible for each of the alloys studied. Differences in fabrication procedure and heat treatment used in production may cause more variation in properties for the alloys under consideration than are caused by wide differences in chemical composition. For this reason it should be understood that in the case of each alloy, the reported properties apply only to the alloy when produced under similar conditions.

INTRODUCTION

The study which is the subject of this report is a part of an experimental metallurgical investigation sponsored by the National Advisory Committee for Aeronautics at the University of Michigan since October 1941. The entire study has had as its main purpose the development of improved materials for use in turbosuperchargers. This report presents the results of an examination of a selected group of metal alloys to determine their suitability for service at 1350° F by a study of their rupture-test characteristics at this elevated temperature.

Since its inception, the research activities of the NACA in the field of materials for exhaust gas turbines has been directed by a Special Subcommittee on Metals for Turbosupercharger Wheels and Buckets. The membership of this Subcommittee is as follows:

Mr. W. L. Badger, General Electric Company, Chairman
Mr. Lewis S. Bergen, Crucible Steel Company
Mr. V. Browne, Allegheny Ludlum Steel Corporation
Mr. C. T. Evans, Jr., Universal-Cyclops Steel Corporation
Mr. Russell Franks, Union Carbide & Carbon Research Laboratories, Inc.
Dr. Marcus A. Grossmann, Carnegie-Illinois Steel Corporation
Dr. George W. Lewis, NACA (ex officio)

The investigation has, under the direction of this Subcommittee, been quite definitely limited to the development of materials for use in turbosupercharger wheels.

This application called for the best possible combination of load-carrying ability at 1200° F and high room-temperature yield strength. These requirements are still receiving a major emphasis in the Committee's research, special attention being given to the effect of fabrication variables.

Two advance confidential reports of the NACA on previous studies (references 1 and 2) have made the results of these investigations in high-temperature metallurgical research available to design engineers. The reports were limited to an account of the room-temperature properties and to rupture-test characteristics at 1200° F of a large number of alloys.

The present report extends the information presented in the two previous reports to include rupture-test characteristics at 1350° F for a group of 13 wrought and 4 cast alloys which, on the basis of their superior properties at other temperatures, appeared promising for service at 1350° F. The physical properties of the wrought materials at room temperatures and at 1200° F, which were available from the previous reports, have been included in this report. While similar data for the 4 cast alloys were not available, considerable information regarding their properties at higher temperatures may be found in the literature, especially in reports of the National Defense Research Committee (references 3 and 4). This report includes, besides the tabulation of data, photomicrographs, stress-rupture time curves at 1200° F and 1350° F, and time-elongation curves for the tests at 1350° F.

TEST MATERIALS

The details of composition and fabrication of both the wrought and the cast materials investigated for their rupture-test characteristics at 1350° F are given with the tabulated data. The choice of actual composition, in each case, was based on the notably superior properties of the alloy at 1200° or at 1500° F, since such an alloy seemed likely to have superior qualities also at 1350° F.

Since fabrication procedure was known to influence their high-temperature properties to a marked degree, many of these wrought alloys were studied after they had been subjected to two or three different methods of fabrication.

The types of fabrication procedure presented included annealing, rolling to 25-percent reduction at 1700° F, rolling to 25-percent reduction at 1200° F, plain forging, and age-hardening. Not all of these conditions were represented by any one alloy, but each condition was represented by at least one alloy.

All machined test specimens were prepared from bar stock approximately 7/8 inch square or round. The bar stock, which was the same as that used for previous work at 1200° F, was supplied by the Crucible Steel Company, International Nickel Company, Inc., The Timken Roller Bearing Company, the Union Carbide and Carbon Research Laboratories, Inc., and the Universal-Cyclops Steel Corporation. All wrought alloys were reported as commercially forgeable and machinable by the contributors in whose plants the bar stock was fabricated. It was recognized, however, that these reports were based on considerable experience with highly alloyed materials intended for service at elevated temperatures. Working and machining alloys chosen for this research were, in most cases, difficult and required special techniques, not to be compared with those used for ordinary carbon steel. In the preparation of the test specimens from bar stock, carbide tools and low cutting speeds were used.

The cast alloys were cast to size with threads by the Dental Investment Process. Four compositions were studied after aging for 50 hours at 1500° F. In addition one composition was aged at 1350° F in preparation for testing. The specimens were supplied by National Research Council Project No. 8 from stock cast by Haynes-Stellite Company.

TEST PROCEDURE

The rupture-test specimens were obtained from the bar stock by splitting it lengthwise into four sections and machining specimens 0.160 inch in diameter with a 1-inch gage length. The cast materials were received as 0.250-inch diameter specimens with a 1-inch gage length. Threads were cast on the specimens and no machining was necessary. All specimens were heat-treated by those supplying them before being submitted for testing.

Rupture tests were conducted at 1350° F in single specimen units with individual controllers. The stresses were applied by simple beams through a system of knife edges. All testing conditions were in accordance with A.S.T.M. recommended procedure for high-temperature tension testing. The stresses were selected to give times for fracture which would establish the 100- and 1000-hour rupture strengths. At least three tests with rupture times varying between 100 and 1000 hours are necessary to establish the two desired rupture strengths. In several cases enough test material was not available for the necessary number of tests, and the data are therefore incomplete.

Time-elongation curves were obtained for the longer rupture tests by measuring the drop of the beam as the specimen elongated. In calculating the elongation of the specimen the assumption was made that all the elongation occurred in the gage section of the specimen. This assumption is believed justified because the ratio of cross-sectional areas of specimens to adapters was such that the stress on the adapters was negligible. In general, the elongation obtained from the strain gage agreed quite well with that measured on the broken specimen from gage marks. The time-elongation curves do not include the deformation which occurred when the specimen was loaded.

In addition to the rupture tests, the following metallurgical tests were made:

1. Hardness tests before and after rupture testing. The Vickers hardness was measured before testing on one specimen. Similar measurements were made near the fracture of the rupture specimen tested under the lowest load.

2. Metallographic examinations. These were made on original samples and the lowest stress test specimen after fracture. The sections examined corresponded in location in both cases. One half of the broken rupture test specimens were split lengthwise and polished. Photomicrographs of the fracture at 100 diameters and the structure of the metal at 1000 diameters were taken.

3. Ductility determinations on the rupture-test specimens. Elongation was measured by obtaining the change in length of the gage section from gage marks and reduction of area by measuring the reduction in cross-sectional area of the broken specimens.

Results of the tensile tests and the rupture tests at 1200° F for the wrought materials were available from a previous investigation. In this previous study the tensile tests were conducted on standard 0.505-inch diameter specimens by applying loads in increments of 2500 pounds per square inch and measuring the deformation after each increment with a modified Martens extensometer system. This procedure was used until the yield point was exceeded; the extensometer system was then removed and the tensile strength determined at a free head speed of 0.03 inch per minute on a 60,000-pound hydraulic tensile machine. The sensitivity of the extensometer system was 0.000003 inch per inch. The data were plotted on cross-sectional paper which permitted determination of proportional limit and offset-yield stress values to within 500 pounds per square inch. The 1200° F specimens were held at temperature 1 hour before testing.

The rupture tests at 1200° F were conducted in the same manner as those at 1350° F, except that time-elongation data were not taken.

RESULTS

The results of this study are presented in a series of three pages of information for each test material. These are, for convenience, set forth in the section following the text, pages 14 to 106. The following information is given for each wrought material, except in those cases where test material was insufficient for all tests:

1. A table of information and data which presents:
 - (a) The chemical composition of the alloy
 - (b) The fabrication procedure and heat treatments used in preparing the test-bar stock
 - (c) Brinell hardness of the bar stock
 - (d) Tensile properties at room temperature and at 1200° F
 - (e) Rupture-test data at 1200° and at 1350° F
2. A page of curves which includes:
 - (a) Logarithmic stress-rupture time curves for the 1200° and 1350° F rupture tests
 - (b) Time-elongation curves for the more prolonged rupture tests at 1350° F

3. A page of photomicrographs which show:

 (a) Microstructure before rupture testing
 (b) The microstructure at the fracture of the rupture-test specimen tested under lowest stress at 1200° F
 (c) The microstructure at the fracture of the rupture-test specimen tested under the lowest stress at 1350° F
 (d) Vickers hardness of each sample at the location of the photomicrographs

Note.- The original magnifications of the photomicrographs were 100 and 1000 diameters. These were reduced 30 percent in reproduction.

The same information is given for cast materials, except that tensile-test and 1200° F rupture-test data were not available.

A graphical comparison of the most important properties of the alloys is presented in figure 32.

The properties indicated by the tabulation should be considered as representative of what has been achieved under controlled experimental conditions. The data presented are the results of a series of tests on one particular heat with one particular sequence of treatments. Samples obtained from small experimental induction heats may have a different level of properties than would be obtained from production heats processed under commercial practice. Furthermore, a certain amount of normal variation from heat to heat may be expected.

The most important conditions to be considered in applying the results from the wrought materials is that the properties both at room temperature and at elevated temperature are markedly affected by the final fabrication procedures. These include heat treatments, temperature of working, method of working the metal, amount of reduction between 1700° F and room temperature, and, in fact, all variations in temperature and methods of working and the sequence of operations. It is extremely important that the manufacturers of the materials should be consulted for information regarding probable effects of such variables in commercial applications.

In applying the data on cast alloys consideration should be given to possible variations resulting from casting sections of other sizes and from heat to heat variations. Likewise, other physical properties should be determined so that consideration could be given to such factors as creep strength and structural stability.

In those cases where erratic-stress versus rupture-time data were obtained, the sample may have been non-uniform. There are, however, some alloys in which a scatter of results is characteristic of the material and was probably caused by structural changes in the metal during testing at elevated temperatures. The agreement between duplicate tensile-test results is a good measure of the uniformity of the material.

The reported rupture strengths are accurate to within at least 1000 pounds per square inch when the test material was uniform. When the data were erratic, average curves were drawn to establish the rupture strengths. In other cases the data were incomplete because sufficient specimens were not available to give complete curves. The rupture strength in such cases can be best approximated by referring to the stress-rupture time curves.

The time-elongation curves are primarily useful for showing the type of deformation characteristic of the alloys. In other words, they indicate the relative amounts of initial deformation in the first stage of creep and whether or not the alloy has a considerable period of increasing deformation rate before fracture. The curves also give an indication of the change in deformation characteristics with increasing time to rupture. Creep rates and total deformations at definite time periods should only be considered as indicative of the behavior of the alloy. The data were obtained by the drop-of-the-beam method, and include, therefore, all deformations which may have occurred in the system during the tests. The accuracy of the strain gages was 0.0001 inch per inch. In general, the curves give creep rates which are quite reliable. Total deformations, however, may be in error by as much as 1 percent.

DISCUSSION OF RESULTS

In considering the results of the tests, the data will first be analyzed with reference to the relative merits of the various alloys, and a theoretical interpretation of the results will then be given.

Analysis of Data

The comparative properties of the various alloys studied in this investigation can best be seen by reference to the graph displayed as page 107. It represents a comparison of room temperature yield strengths, 1200° and 1350° F rupture strengths, and ductility characteristics.

On the basis of rupture strengths at 1350° F the outstanding wrought alloys were 19-9W-MoM (19-9 DL), N153 rolled at 1200° F and the Low-Carbon N153, N154 and N155 alloys. In addition to high strength the Low-Carbon N153, N154, and N155 alloys also had high ductility in the rupture test. The outstanding cast alloy was 422-19, although all the cast alloys had high 1000-hour strengths with good hot ductility

The best wrought alloys had 100- and 1000-hour rupture strengths up to 36,000 and up to 27,500 pounds per square inch, respectively, at 1350° F. Corresponding values for the cast alloys varied between 32,000 and 47,000 pounds per square inch for the 100-hour strength and 25,000 to 36,000 pounds per square inch for the 1000-hour strength.

The wrought alloys which were tested in more than one condition of treatment indicate the following trends:

1. Annealed materials have the lowest room temperature strengths and 1200° and 1350° F rupture strengths At room temperature and at 1350° F they tend to have high ductility.

2. Rolling 25 percent at 1700° F after an annealing treatment increased both room-temperature and elevated-temperature strength properties.

3. Rolling 25 percent at 1200° F gave higher tensile strength at room temperature and higher 100-hour rupture strengths at 1200° F than did rolling at 1700° F. In most cases the 1000-hour rupture strengths at 1200° F were also higher. At 1350° F there was very little difference in rupture strength between the material rolled at 1200° F and that rolled at 1700° F with one exception. Gamma Columbium rolled at 1200° F was much weaker than the same material rolled at 1700° F.

4. In general the materials rolled at 1700° F had the best ductility in the rupture tests.

The photomicrographs and the hardness data indicate that the materials tested at 1200° F are quite stable at that temperature. The only indication of instability was the low elongations in the longer-time rupture tests.

At 1350° F, however, the microstructures showed considerably more evidence of alteration during rupture testing. Likewise there was a greater change in hardness. Most of the materials, however, had a very satisfactory degree of stability. Exceptions were 234-A-5, Gamma Columbium rolled at 1200° F and Age-Hardenable Inconel. These three materials all had low rupture strength at 1350° F accompanied by pronounced microstructural changes and decreases in hardness. Alloy 19-9W-MoM also showed evidence of instability through the wide difference between 100- and 1000-hour rupture strengths, microstructural alteration, and hardness decrease, even though its strengths were very high.

The castings varied widely from the wrought materials in that the gage sections appeared to consist of only a few grains, possibly only 6 to 8 along a central axis. After fracture at 1350° F the rupture specimens had a rough, uneven appearance as a result of each of the few large grains deforming in a different way. The microstructures, after aging, were a solid solution matrix, containing large particles of an excess constituent, and fine particles of some other constituent, or possibly the same, precipitated in the matrix near the large particles. This structure gave the metal a cellular appearance with the excess constituents forming the cell boundaries. After rupture testing at 1350° F, the fine precipitated particles were more numerous and more uniformly precipitated.

The structures resulting from the two aging treatments on Vitallium are contradictory. The specimens aged at 1350° F prior to testing were from a different heat than those aged at 1500° F, although they were both reported as similar in all other respects. The material aged at 1500° F had considerably less precipitate than that aged at 1350° F and developed very little more during testing. This is contrary to the

usual experience of more precipitation at the higher temperature. This therefore suggests that an unknown heat-to-heat variation was introduced and that the difference in strength after the two treatments may not be due to the heat-treatment.

The time-elongation curves show the deformation characteristics of the alloys at 1350° F. In general, those materials having considerable elongation at fracture had increasing rates of deformation after the first few hours under load. Those materials having a low elongation after fracture had a nearly constant rate of deformation from a few hours after loading until failure.

Theoretical Interpretation of Results

The reasons for the superiority of certain alloys, and of certain processing procedures and heat treatments are not entirely clear. Considerable attention is being given to this problem in other phases of the high-temperature metallurgical research of the NACA. The work is not yet complete, but it is probable that all these high-strength materials obtain their superiority largely through precipitation reactions, and, in the case of wrought alloys, by the added effect of strain-hardening as a result of mechanical working.

Mechanical working of the alloys exerts its influence on the room-temperature and elevated-temperature properties through strain-hardening and control of size and distribution of precipitated constituents. These two factors are closely interrelated and cannot be separated. Strain-hardening probably is the predominating factor at room temperature and 1200° F; while the precipitation characteristics probably control at 1350° F. Mechanical work influences not only the initial size and distribution of precipitated particles, but also the precipitation which occurs during exposure to stress at elevated temperatures for prolonged time periods.

Heat treatments, such as solution and aging treatments, exert their influence by changing the precipitation characteristics of the alloys. This applies both to the initial size and dispersion of precipitated constituents and to those which occur during service at elevated temperatures.

Mechanical work at 1200° F induces more strain-hardening than at 1700° F. The hardness was retained while testing at 1200° F, and the degree of structural alteration

was not great. It is therefore probable that the relief of strain-hardening during 1200° F tests was not great and was balanced by precipitation-hardening. At 1350° F, the materials worked at 1700° F had as high, or higher, rupture strength than those worked at 1200° F. This finding is believed to indicate that strain-hardening was less effective at 1350° F than at 1200° F and that the dispersion of precipitates was more effective.

The increase in hardness of annealed wrought materials and cast alloys during test was due largely to the precipitation reactions. Other manifestations were the ductility characteristics in the rupture tests and the microstructural changes. Precipitation reactions affected ductility characteristics and resulted in the appearance of fine particles in the microstructures.

The low strength of alloy 234-A-5 at 1350° F was due to overaging. Likewise the purely age-hardening Inconel overaged at 1350° F. The low strength of some of the alloys worked at 1200° F prior to testing at 1350° F may have been due to relief of strain-hardening or to the lower stability of the finer precipitation resulting from working at 1200° F.

The relationship between initial treatment of alloys and their subsequent properties has made it impossible to develop correlations between chemical composition and strength properties. Only when the influence of heat-treatment and fabrication procedures has been determined for the various types of alloy compositions will it be possible to relate properties definitely to chemical analysis. For these reasons other fabrication procedures than those used for the test materials of this investigation may result in either lower or higher properties. Many materials, likewise, which have been omitted from this investigation because of low strength at other temperatures, may have equal, or superior, properties when the control of strain-hardening and precipitation characteristics have been worked out.

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1. Anon.: Physical Data of Certain Alloys for High Temperature Applications. NACA ACR, Oct. 1942.

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3. Miller, R. F., and Cross, H. C.: Advisory Report on Survey of Data on Alloys Developed for Turbosupercharger and Gas Turbine Applications (N-102). War Metallurgy Div., NDRC, OSRD, Dec. 27, 1943.

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ALLOY 16-25-6 - Annealed (Timken Alloy)*

MANUFACTURER Ingot obtained from The Timken Roller Bearing Co., Steel and Tube Division, and fabricated by the Universal-Cyclops Steel Corporation

COMPOSITION 0.15% C, 0.84% Si, 1.14% Mn, 16.75% Cr, 25.26% Ni, 6.29% Mo, 0.01% P, 0.022% S, 0.175% N_2

TREATMENT Melted in an electric arc furnace. Hammer forged at 2065/1300°F. to 3/4 inch square bar. Heated 1 hour at 2100°F. and air cooled.

HARDNESS 207 Brinell

TENSILE PROPERTIES

Temperature Deg. F.	Tensile Strength Lb./Sq.In.	Yield Stress Lb./Sq.In. 0.02%	Yield Stress Lb./Sq.In. 0.2%	Proportional Limit Lb./Sq.In.	Elongation % in 2 In.	Reduction of Area %
80	121,375	48,500	59,700	35,000	39.0	51.1
	118,375	45,200	56,300	35,000	40.0	51.3
1200	83,500		36,200	17,500	22.0	21.1
	81,750		35,700	20,000	21.0	19.6

STRESS-RUPTURE DATA

Temperature Deg. F.	Stress Lb./Sq.In.	Time for Rupture Hours	Elongation % in 1 In.	Reduction of Area %
1200	75,000	0.62	18.0	17.3
	67,000	2.67	10.0	16.7
	50,000	89.0	13.0	11.4
	44,000	199.0	17.0	28.2
	35,000	990.0	11.0	21.6
1350	30,000	74.0	33.0	50.1
	25,000	102.5	30.0	47.4
	23,000	171.5	27.0	62.3

STRESS-RUPTURE STRENGTHS
(from stress-rupture time plot)

Time for Rupture Hours	Stress Lb./Sq.In. 1200°F.	Stress Lb./Sq.In. 1350°F.
1	72,000	
10	61,000	
100	49,000	25,500
1000	35,000	

*Alloys 16-25-6 - Annealed, 16-25-6 - Hot Worked and 16-25-6 - "Cold" Worked are from the same billet and differ only in processing.



100X



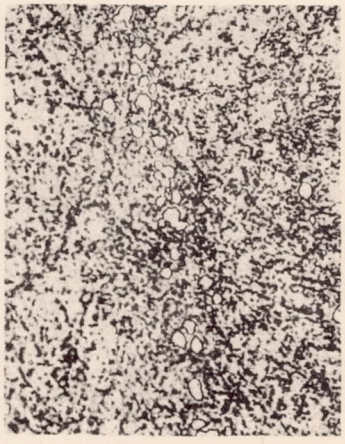
1000X

As Received

Vickers Hardness - 214



Fracture - 100X

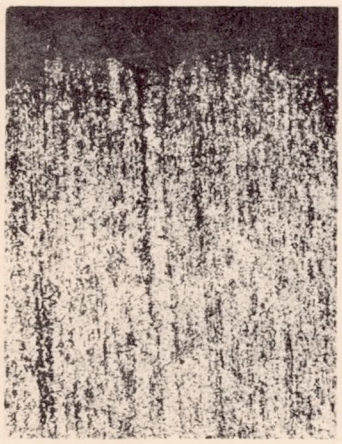


Interior - 1000X

1200°F.

35,000 Lbs. per Sq. In.
990.0 Hrs. to Rupture

Vickers Hardness - 271



Fracture - 100X



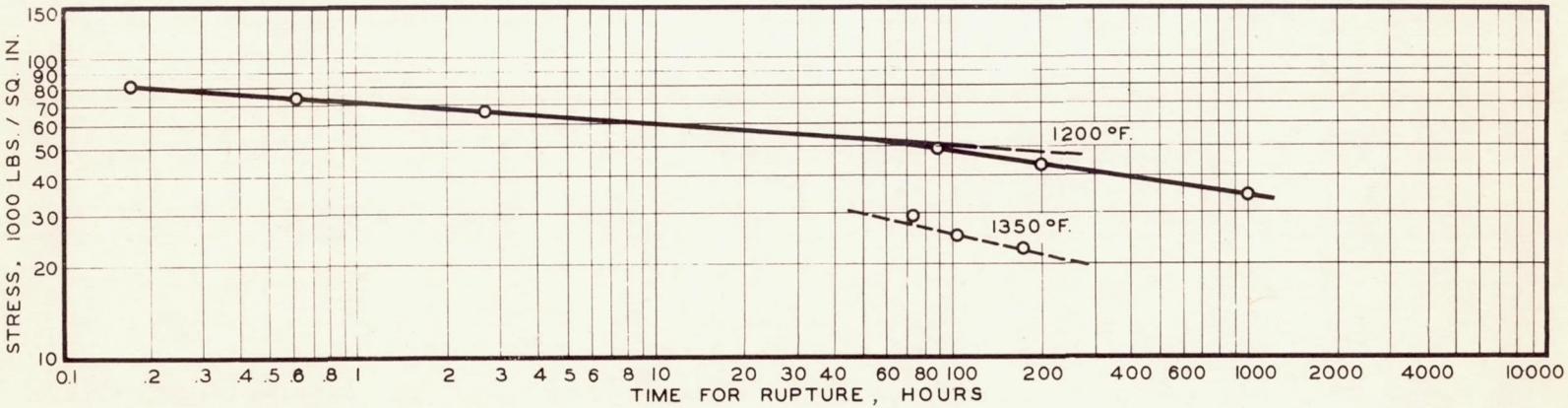
Interior - 1000X

1350°F.

23,000 Lbs. per Sq. In.
171.5 Hrs. to Rupture

Vickers Hardness - 242

MICROSTRUCTURES OF 16-25-6 - ANNEALED (TIMKEN ALLOY)
AS RECEIVED AND AFTER RUPTURE TESTS AT 1200°F. AND 1350°F.



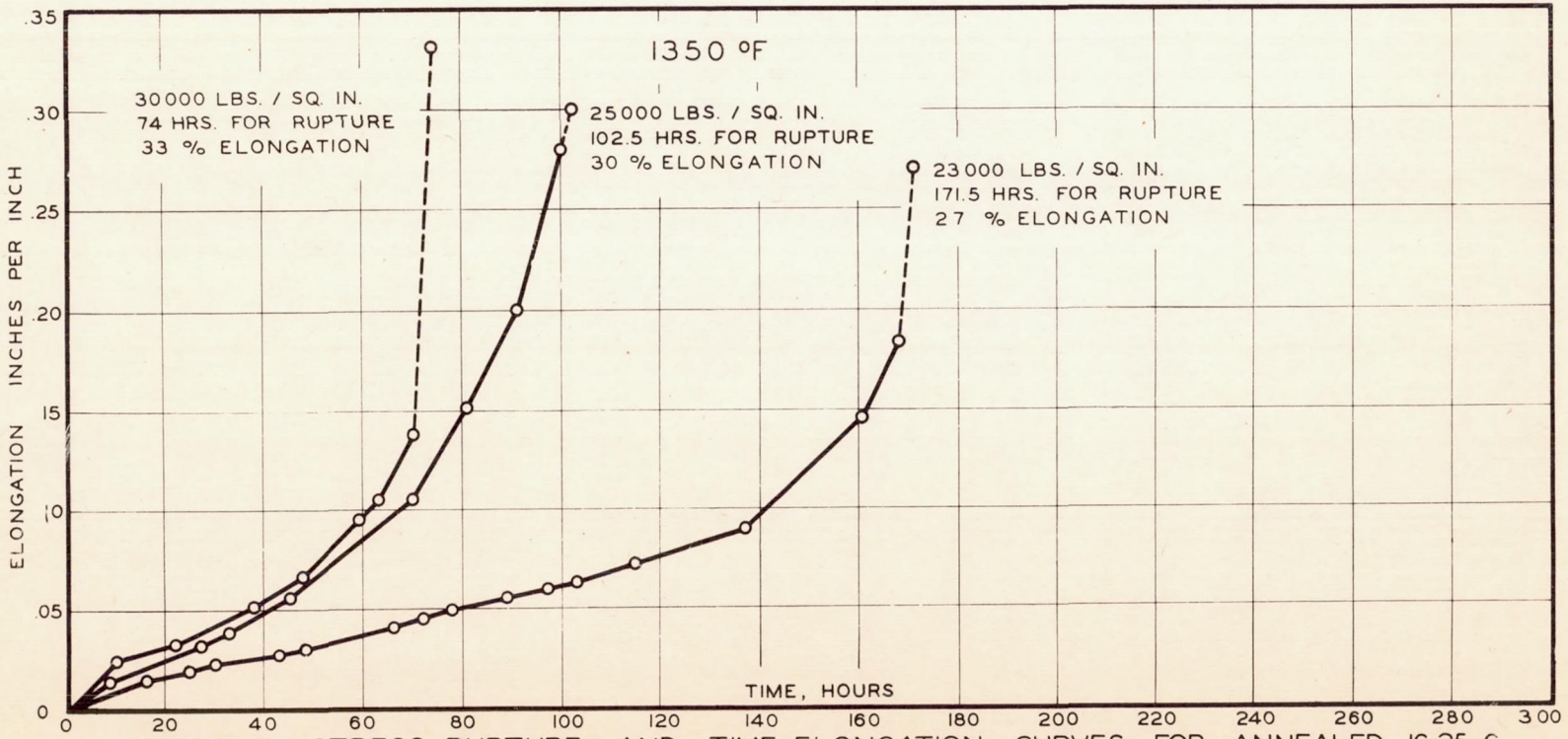


FIGURE 1- STRESS-RUPTURE AND TIME-ELONGATION CURVES FOR ANNEALED 16-25-6

ALLOY 16-25-6 - Hot Worked (Timken Alloy)*

MANUFACTURER Ingot obtained from The Timken Roller Bearing Co., Steel and Tube Division, and fabricated by the Universal-Cyclops Steel Corporation

COMPOSITION 0.15% C, 0.84% Si, 1.14% Mn, 16.75% Cr, 25.26% Ni, 6.29% Mo, 0.175% N_2

TREATMENT Melted in an electric arc furnace. Forged and rolled 2065/1650°F. to 7/8 inch square bar. Heated 1 hour at 2100°F. and air cooled. Reheated to 1700°F. and reduced in area 25.17% by rolling and air cooled. Stress relieved by heating through at 1200°F. and air cooled.

HARDNESS 279 Brinell

TENSILE PROPERTIES

Temperature Deg. F.	Tensile Strength Lb./Sq.In.	Yield Stress Lb./Sq.In. 0.02%	Yield Stress Lb./Sq.In. 0.2%	Proportional Limit Lb./Sq.In.	Elongation % in 2 In.	Reduction of Area %
80	137,500	94,500	111,500	82,500	19.5	35.4
	138,000	95,000	111,500	80,000	18.5	30.8
1200	97,750		76,500	47,500	21.0	36.6
	93,250		76,000	45,000	20.5	36.1

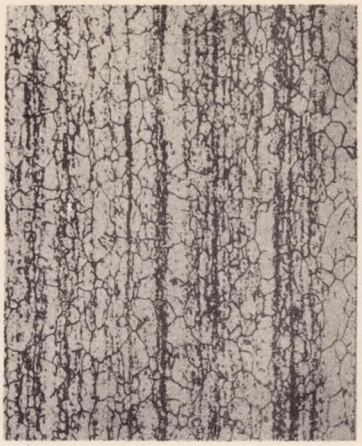
STRESS-RUPTURE DATA

Temperature Deg. F.	Stress Lb /Sq.In.	Time for Rupture Hours	Elongation % in 1 In.	Reduction of Area %
1200	83,000	0.70	22.0	39.4
	75,000	4.73	13.0	26.7
	60,000	38.5	27.0	40.9
	50,000	95.0	28.0	43.7
	48,000	156.5	25.0	34.4
	38,000	1257.5	18.0	24.0
1350	35,000	17.5	30.0	50.2
	28,000	129.0	21.0	52.7

STRESS-RUPTURE STRENGTHS
(from stress-rupture time plot)

Time for Rupture Hours	Stress Lb./Sq.In. 1200°F.	Stress Lb./Sq.In. 1350°F.
1	82,000	
10	69,000	
100	52,000	28,500
1000	39,000	

*Alloys 16-25-6 Annealed, 16-25-6 Hot Worked and 16-25-6 "Cold" Worked are from the same ingot and differ only in processing.



100X



1000X

As Received

Vickers Hardness - 295



Fracture - 100X



Interior - 1000X

1200°F.

38,000 Lbs. per Sq. In.
1257.5 Hrs. to Rupture

Vickers Hardness - 290



Fracture - 100X



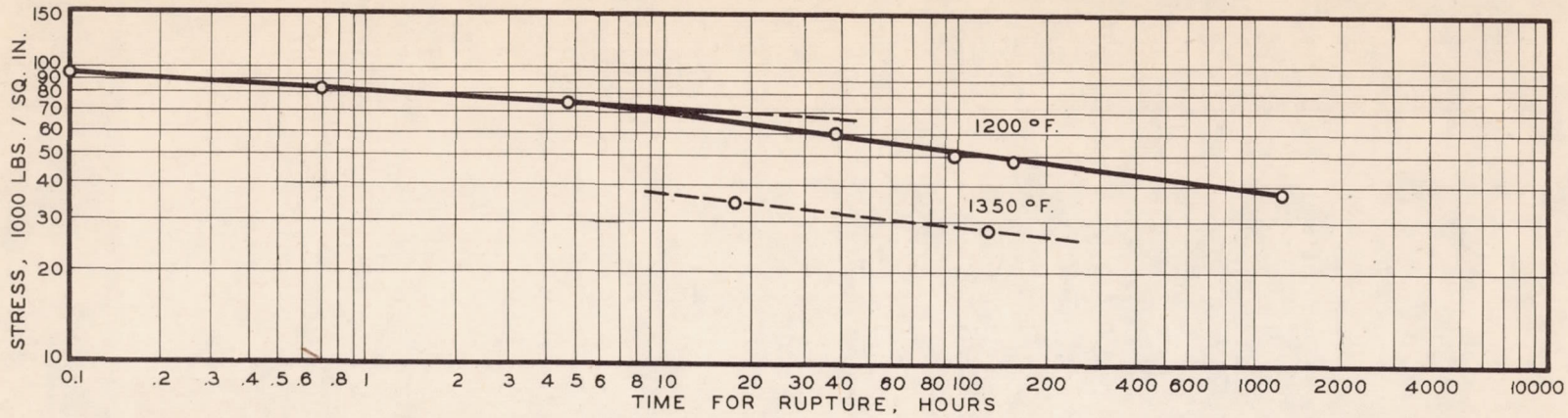
Interior - 1000X

1350°F.

28,000 Lbs. per Sq. In.
129.0 Hrs. to Rupture

Vickers Hardness - 267

MICROSTRUCTURES OF 16-25-6 - HOT WORKED (TIMKEN ALLOY)
AS RECEIVED AND AFTER RUPTURE TESTS AT 1200°F. AND 1350°F.



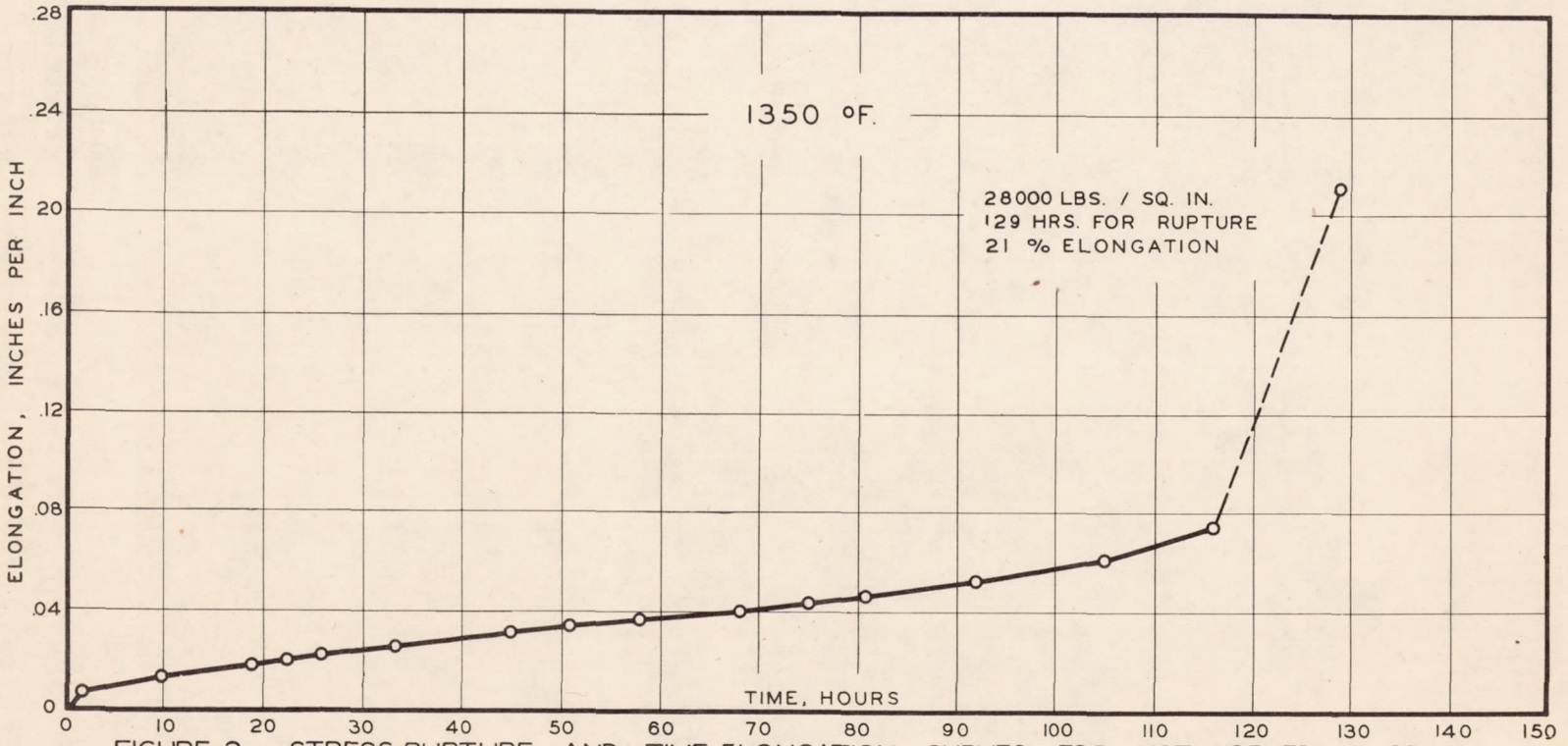


FIGURE 2 - STRESS-RUPTURE AND TIME-ELONGATION CURVES FOR HOT-WORKED 16-25-6

ALLOY 16-25-6 -"Cold" Worked (Timken Alloy)*

MANUFACTURER Ingot obtained from The Timken Roller Bearing Co., Steel and Tube Division, and fabricated by the Universal-Cyclops Steel Corporation

COMPOSITION 0.15% C, 0.84% Si, 1.14% Mn, 16.75% Cr, 25.26% Ni, 6.29% Mo, 0.175% N_2

TREATMENT Melted in an electric arc furnace. Forged and rolled 2065/1650°F. to 7/8 inch square bar. Heated 1 hour at 2100°F. and air cooled. Reheated to 1200°F. and reduced in area 22.53% by rolling and air cooled. Stress relieved by heating through at 1200°F. and air cooled.

HARDNESS 326 Brinell

TENSILE PROPERTIES

Temperature Deg. F.	Tensile Strength Lb./Sq.In.	Yield Stress Lb./Sq.In. 0.02%	Yield Stress Lb./Sq.In. 0.2%	Proportional Limit Lb./Sq.In.	Elongation % in 2 In.	Reduction of Area %
80	162,250	121,000	143,500	102,500	15.5	33.8
	161,750	117,000	143,500	92,500	16.0	34.1
1200	105,250		92,500	62,500	14.0	28.8
	107,500		94,000	60,000	13.0	27.9

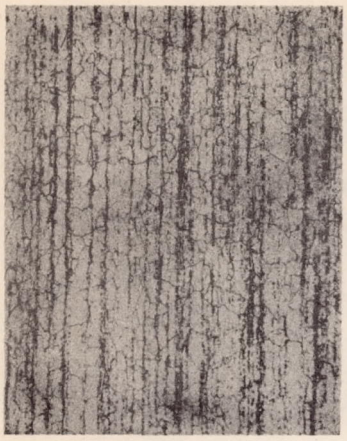
STRESS-RUPTURE DATA

Temperature Deg. F.	Stress Lb./Sq.In.	Time for Rupture Hours	Elongation % in 1 In.	Reduction of Area %
1200	96,000	0.95	7.0	15.6
	90,000	1.70	6.0	22.3
	65,000	35.0	11.0	18.9
	54,000	125.5	8.0	7.7
	52,000	354.0	6.0	14.3
	41,000	1207.0	4.0	1.0
1350	35,000	24.5	7.0	22.4
	31,000	78.0	3.0	3.7
	28,000	147.0	5.0	6.1
	24,000	189.5	3.0	5.0
	20,000	704.5	2.0	2.4

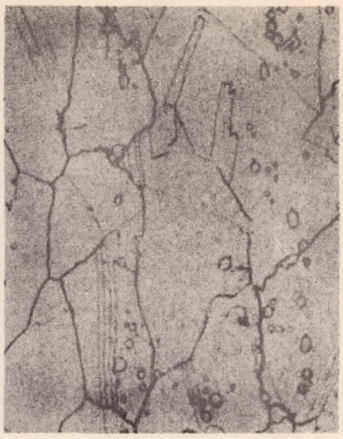
STRESS-RUPTURE STRENGTHS
(from stress-rupture time plot)

Time for Rupture Hours	Stress Lb./Sq.In. 1200°F.	Stress Lb./Sq.In. 1350°F.
1	94,000	
10	78,000	
100	57,000	28,000
1000	42,000	19,000

*Alloys 16-25-6 Annealed, 16-25-6 Hot Worked and 16-25-6 "Cold" Worked are from the same ingot and differ only in processing.



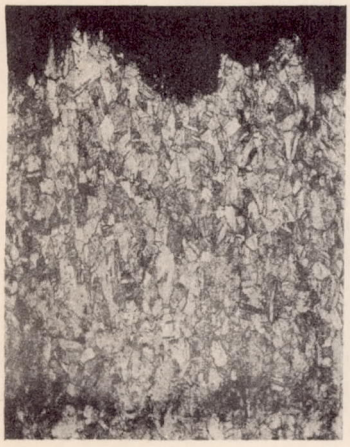
100X



1000X

As Received

Vickers Hardness - 348



Fracture - 100X



Interior - 1000X

1200°F.

41,000 Lbs. per Sq. In.
1207.0 Hrs. to Rupture

Vickers Hardness - 316



Fracture - 100X



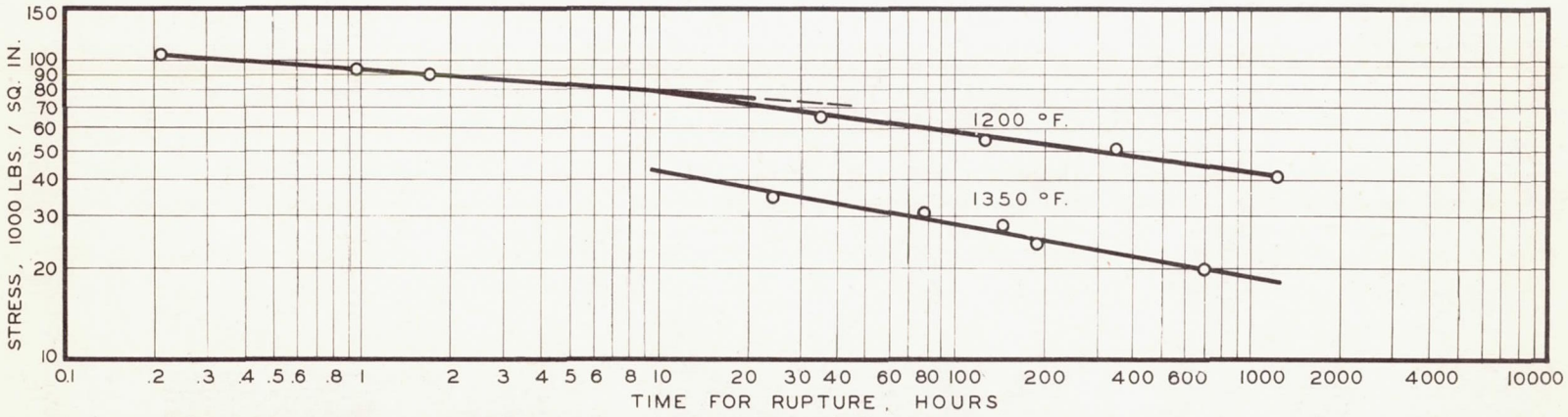
Interior - 1000X

1350°F.

20,000 Lbs. per Sq. In.
704.5 Hrs. to Rupture

Vickers Hardness - 282

MICROSTRUCTURES OF 16-25-6 - COLD WORKED (TIMKEN ALLOY)
AS RECEIVED AND AFTER RUPTURE TESTS AT 1200°F. AND 1350°F.



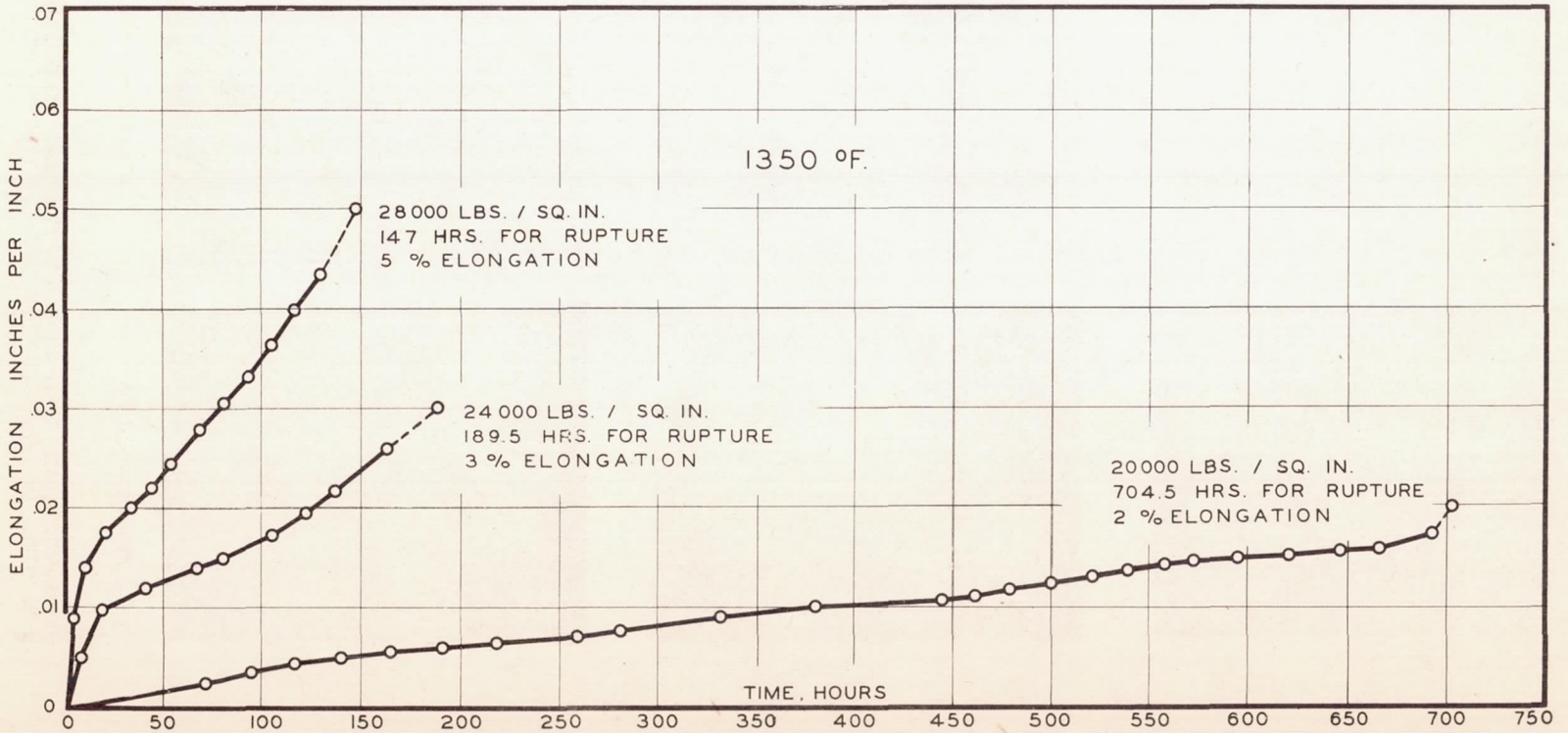


FIGURE 3 - STRESS-RUPTURE AND TIME-ELONGATION CURVES FOR COLD-WORKED 16-25-6

ALLOY 19-9W-Mo (R1956)

MANUFACTURER Universal-Cyclops Steel Corporation

COMPOSITION 0.11% C, 0.56% Si, 0.55% Mn, 18.80% Cr, 8.54% Ni, 0.38% Mo, 1.27% W, 0.45% Cb, 0.39% Ti

TREATMENT Melted in an induction furnace; 33 pound heat. Hammer Cogged at 2055/1300°F. to 7/8 inch square bars. Heated to 2000°F. for 1 hour and air cooled. Reheated to 1200°F. and reduced in area 25.95% by rolling. Stress relieved by heating through at 1200°F. and air cooled.

HARDNESS 251 Brinell

TENSILE PROPERTIES

Temperature Deg. F.	Tensile Strength Lb./Sq.In.	Yield Stress Lb./Sq.In. 0.02%	Yield Stress Lb./Sq.In. 0.2%	Proportional Limit Lb./Sq.In.	Elongation % in 2 In.	Reduction of Area %
80	114,400	61,000	88,500	36,000	33.5	53.3
	114,000	75,000	91,000	57,500	35.0	52.2
1200	72,700		63,500	32,500	18.0	53.8
	73,000		65,000	30,000	16.5	47.8
	73,125		64,000	35,000	17.5	47.8

STRESS-RUPTURE DATA

Temperature Deg. F.	Stress Lb./Sq.In.	Time for Rupture Hours	Elongation % in 1 In.	Reduction of Area %
1200	65,000	0.38	9.0	57.7
	60,000	5.93	12.0	42.8
	55,000	71.0	11.0	37.9
	50,000	199.0	10.0	23.4
	42,000	973.0	6.0	10.2
1350	30,000	76.0	12.0	25.6
	26,000	164.5	11.0	28.8

STRESS-RUPTURE STRENGTHS
(from stress-rupture time plot)

Time for Rupture Hours	Stress Lb./Sq.In. 1200°F.	Stress Lb./Sq.In. 1350°F.
1	64,000	
10	59,000	
100	54,500	28,500
1000	42,000	



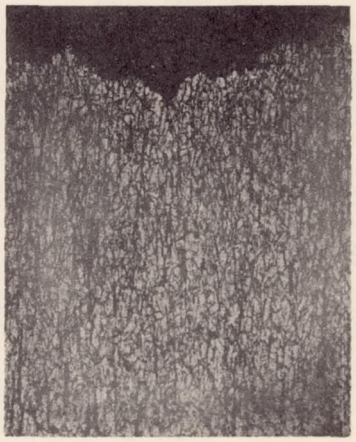
100X



1000X

As Received

Vickers Hardness - 252



Fracture - 100X

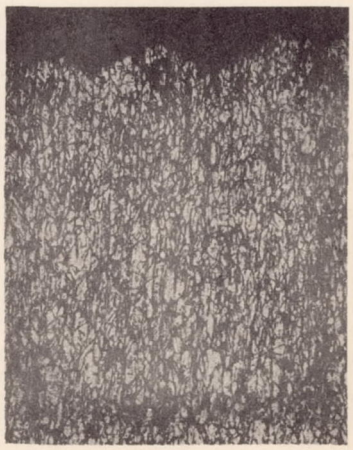


Interior - 1000X

1200°F.

42,000 Lbs. per Sq. In.
973.0 Hrs. to Rupture

Vickers Hardness - 261



Fracture - 100X



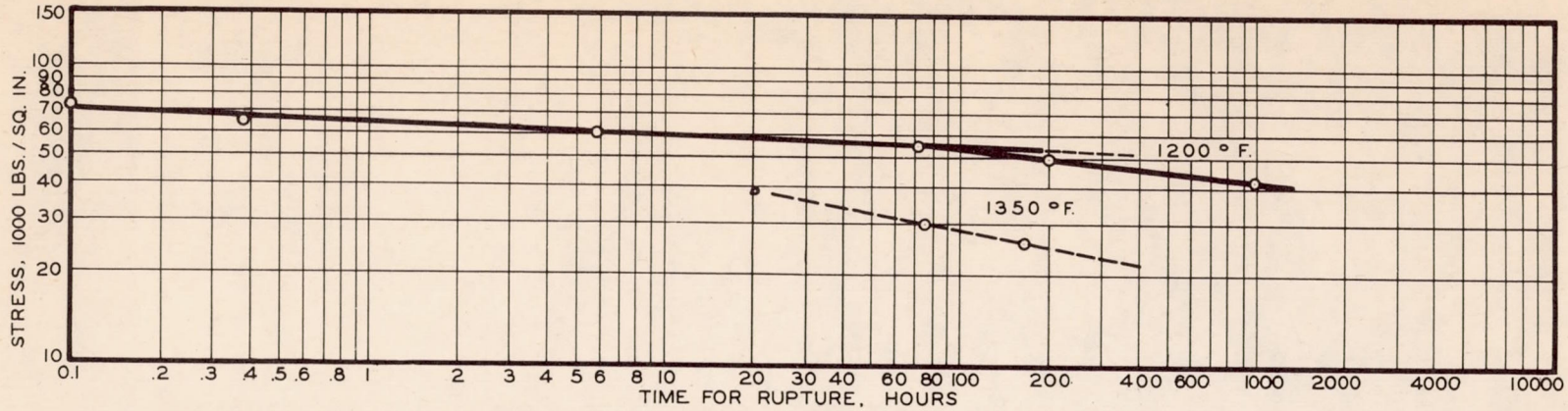
Interior - 1000X

1350°F.

26,000 Lbs. per Sq. In.
164.5 Hrs. to Rupture

Vickers Hardness - 241

MICROSTRUCTURES OF ALLOY 19-9W-Mo - COLD WORKED
AS RECEIVED AND AFTER RUPTURE TESTS AT 1200°F. AND 1350°F.



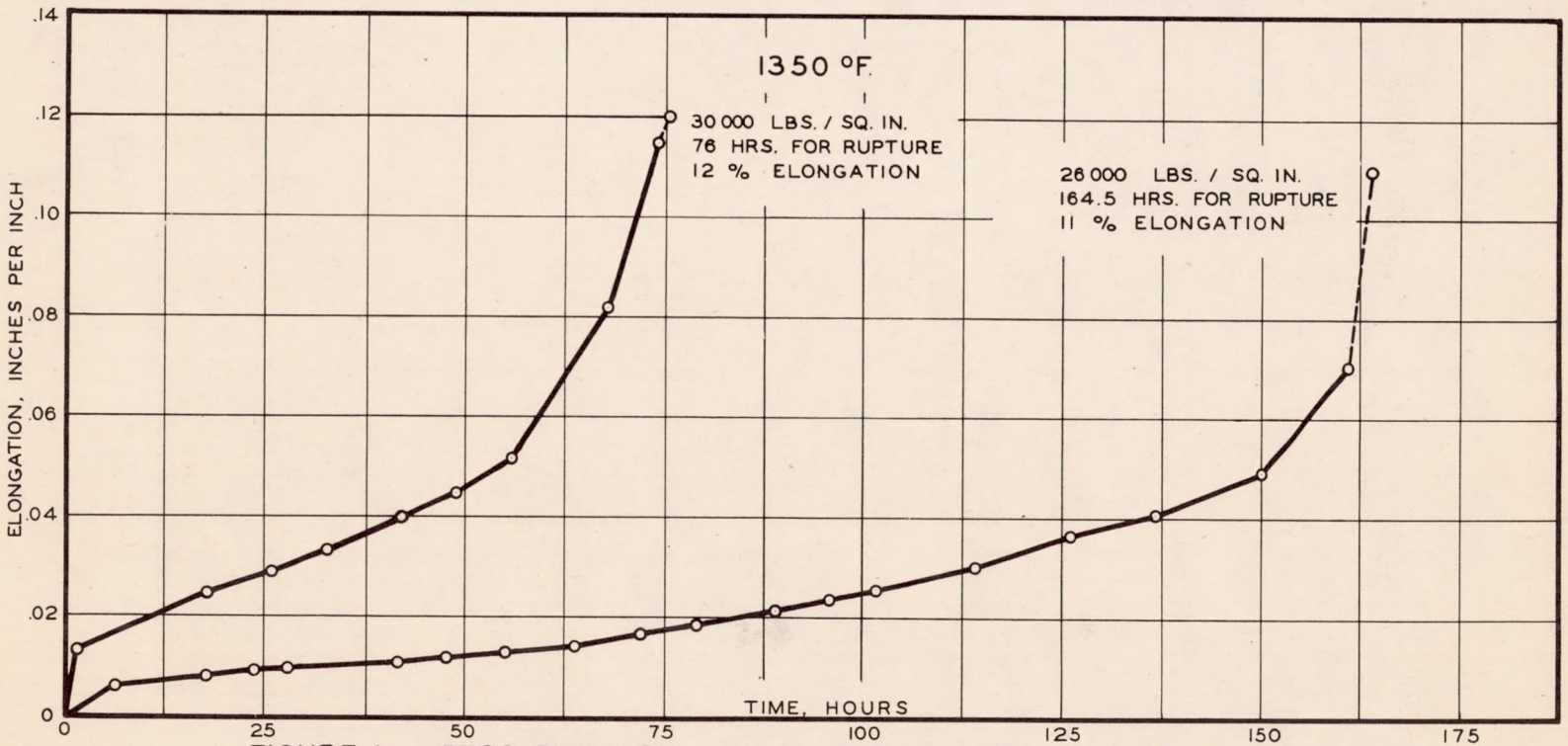


FIGURE 4- STRESS-RUPTURE AND TIME-ELONGATION CURVES FOR 19-9 WMo

ALLOY 19-9 DL (19-9W-MoM) (R1803)

MANUFACTURER Universal-Cyclops Steel Corporation

COMPOSITION 0.26% C, 0.57% Si, 0.52% Mn, 18.95% Cr, 9.05% Ni, 1.22% Mo, 1.19% W, 0.29% Cb, 0.21% Ti

TREATMENT Melted in an induction furnace; 33 pound heat. Hammer forged at 2055/1300°F. to 7/8 inch square bars. Heated 1 hour at 2100°F. and air cooled. Reheated to 1200°F. and reduced in area 21.35% by rolling. Stress relieved by heating through at 1200°F. and air cooled.

HARDNESS 289 Brinell

TENSILE PROPERTIES

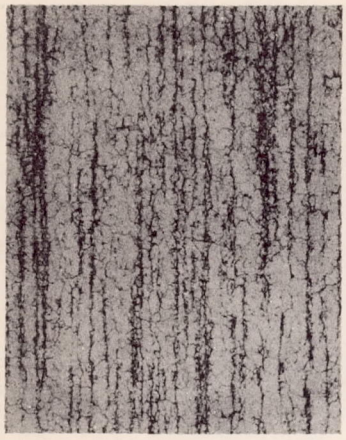
Temperature Deg. F.	Tensile Strength Lb./Sq.In.	Yield Stress Lb./Sq.In. 0.02%	Yield Stress Lb./Sq.In. 0.2%	Proportional Limit Lb./Sq.In.	Elongation % in 2 In.	Reduction of Area %
80	136,750	95,000	112,500	75,000	28.5	48.4
	140,750	95,000	115,000	75,000	29.0	48.1
1200	91,000		81,000	52,500	16.0	38.8
	87,750		77,500	52,500	15.5	39.8

STRESS-RUPTURE DATA

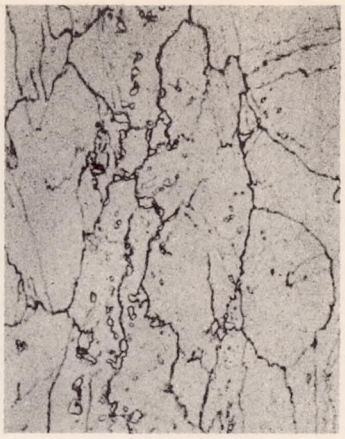
Temperature Deg. F.	Stress Lb./Sq.In.	Time for Rupture Hours	Elongation % in 1 In.	Reduction of Area %
1200	78,000	1.30	10.0	28.8
	73,000	3.13	8.0	25.0
	60,000	202.0	3.0	7.3
	55,000	383.0	2.0	6.1
	50,000	1027.0	3.0	7.9
1350	35,000	101.0	4.0	5.0
	30,000	204.0	3.0	7.4
	26,000	362.0	5.0	3.7

STRESS-RUPTURE STRENGTHS
(from stress-rupture time plot)

Time for Rupture Hours	Stress Lb./Sq.In. 1200°F.	Stress Lb./Sq.In. 1350°F.
1	79,000	
10	70,000	
100	62,000	35,000
1000	50,000	20,500



100X



1000X

As Received

Vickers Hardness - 319



Fracture - 100X

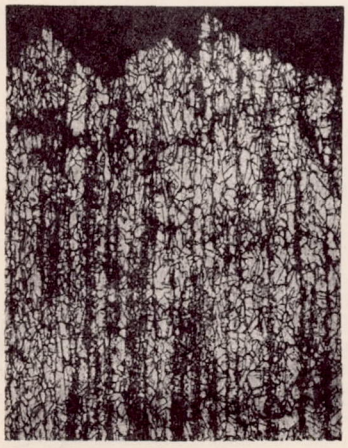


Interior - 1000X

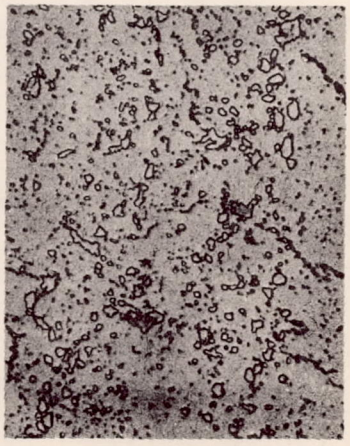
1200°F.

50,000 Lbs. per Sq. In.
1027.0 Hrs. to Rupture

Vickers Hardness - 334



Fracture - 100X



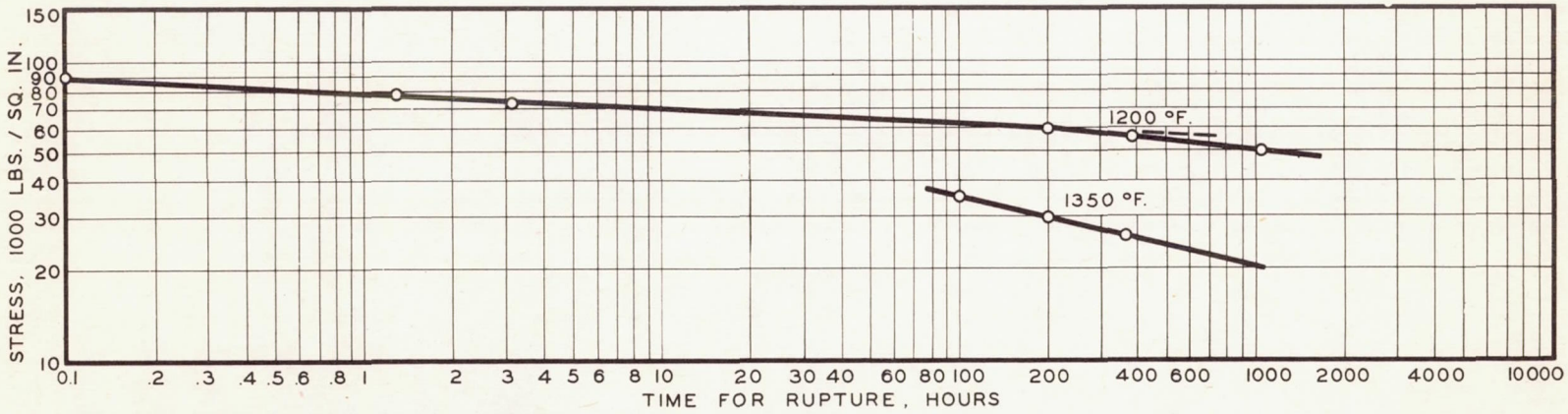
Interior - 1000X

1350°F.

26,000 Lbs. per Sq. In.
362.0 Hrs. to Rupture

Vickers Hardness - 294

MICROSTRUCTURES OF ALLOY 19-9W-MoM - COLD WORKED
AS RECEIVED AND AFTER RUPTURE TESTS AT 1200°F. AND 1350°F.



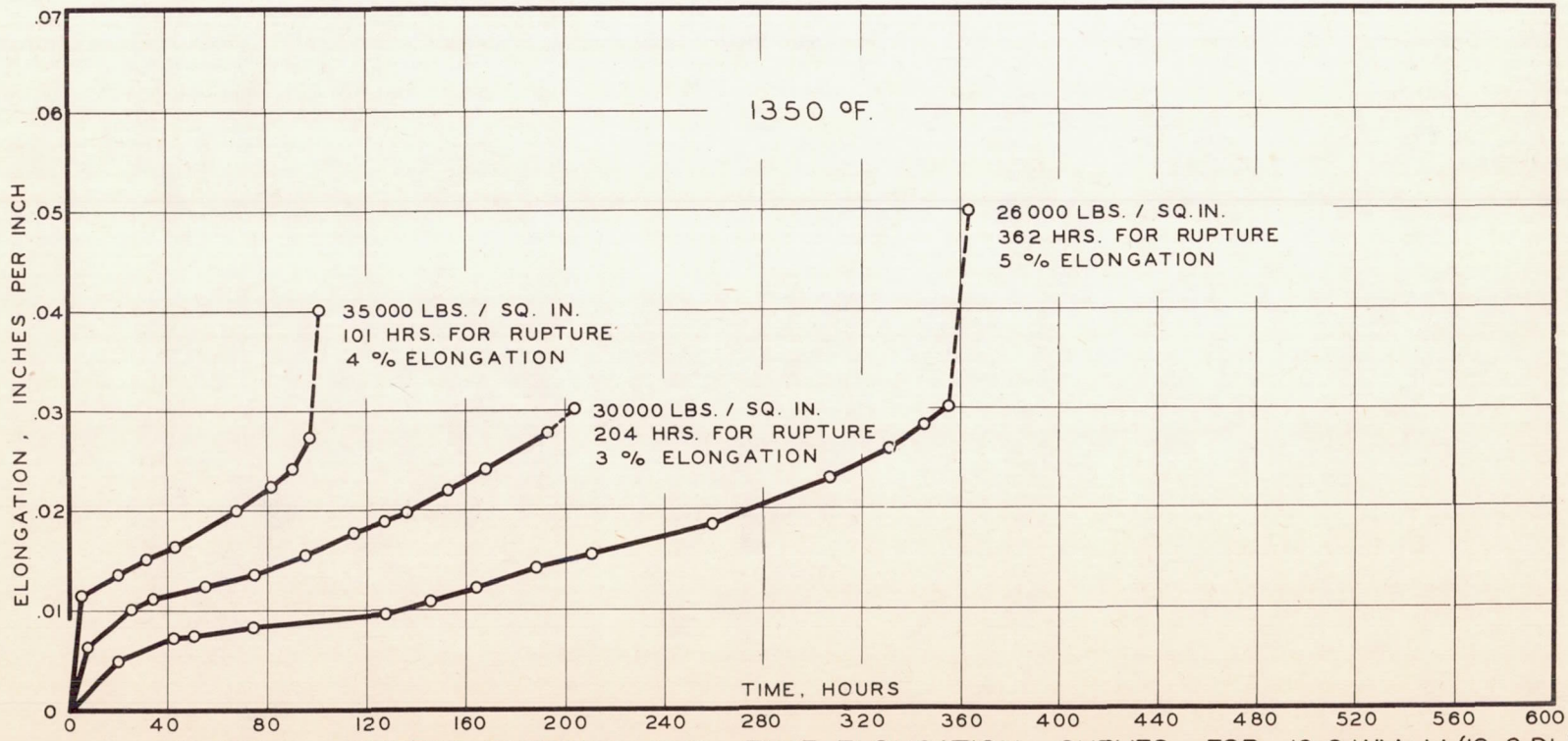


FIGURE 5 - STRESS-RUPTURE AND TIME-ELONGATION CURVES FOR 19-9 WMo M (19-9 DL)

ALLOY 234-A-5

MANUFACTURER Crucible Steel Company of America

COMPOSITION 0.38% C, 0.30% Si, 4.17% Mn, 18.52% Cr, 4.55% Ni, 1.35% Mo, 1.34% W, 0.57% Cb.

TREATMENT 150 lb. induction furnace heat. Hammer forged. Finished at about 1200°F. and stress relieved for 1 hour at 1200°F.

HARDNESS 292 Brinell

TENSILE PROPERTIES

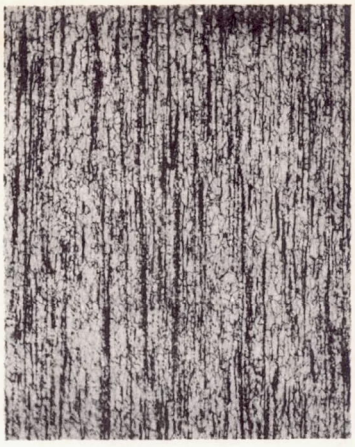
Temperature Deg. F.	Tensile Strength Lb./Sq.In.	Yield Stress Lb./Sq.In. 0.02%	Yield Stress Lb./Sq.In. 0.2%	Proportional Limit Lb./Sq.In.	Elongation % in 2 In.	Reduction of Area %
80	151,000	87,500	106,000	62,500	13.2	13.4
	155,500	81,800	104,700	55,000	22.5	31.1
1200	78,000		65,000	30,000	20.0	48.2
	79,500		67,500	32,500	19.5	44.7

STRESS-RUPTURE DATA

Temperature Deg. F.	Stress Lb./Sq.In	Time for Rupture Hours	Elongation % in 1 In.	Reduction of Area %
1200	68,000	0.34	22.0	49.2
	62,000	2.96	18.0	56.9
	55,000	54.0	26.0	60.0
	50,000	83.0	27.0	60.9
	46,000	231.5	16.0	46.5
	45,000	468.0	18.0	41.8
	40,000	535.0	12.0	39.0
1350	30,000	26.0	28.0	66.2
	26,000	66.0	28.0	57.7
	22,000	131.5	25.0	39.3
	18,000	224.0	30.0	43.1
	13,000	832.5	20.0	23.2

STRESS-RUPTURE STRENGTHS
(from stress-rupture time plot)

Time for Rupture Hours	Stress Lb./Sq.In. 1200°F.	Stress Lb./Sq.In. 1350°F.
1	65,000	
10	58,000	
100	50,000	22,500
1000	39,000	12,500



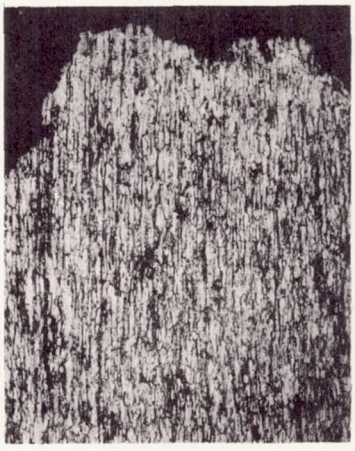
100X



1000X

As Received

Vickers Hardness - 318



Fracture - 100X

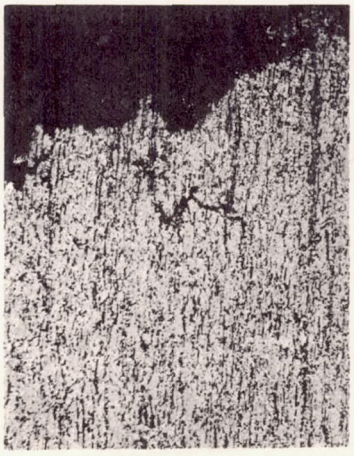


Interior - 1000X

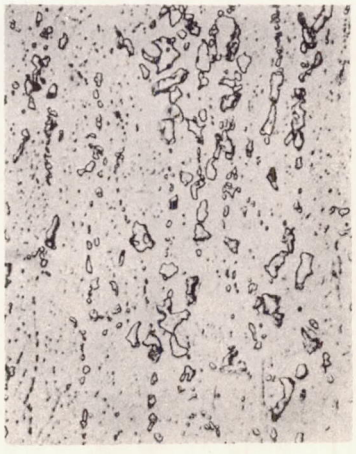
1200°F.

40,000 Lbs. per Sq. In.
535.0 Hrs. to Rupture

Vickers Hardness - 315



Fracture - 100X



Interior - 1000X

1350°F.

13,000 Lbs. per Sq. In.
832.5 Hrs. to Rupture

Vickers Hardness - 276

MICROSTRUCTURES OF ALLOY 234-A-5 - FORGED
AS RECEIVED AND AFTER RUPTURE TESTS AT 1200°F. AND 1350°F.

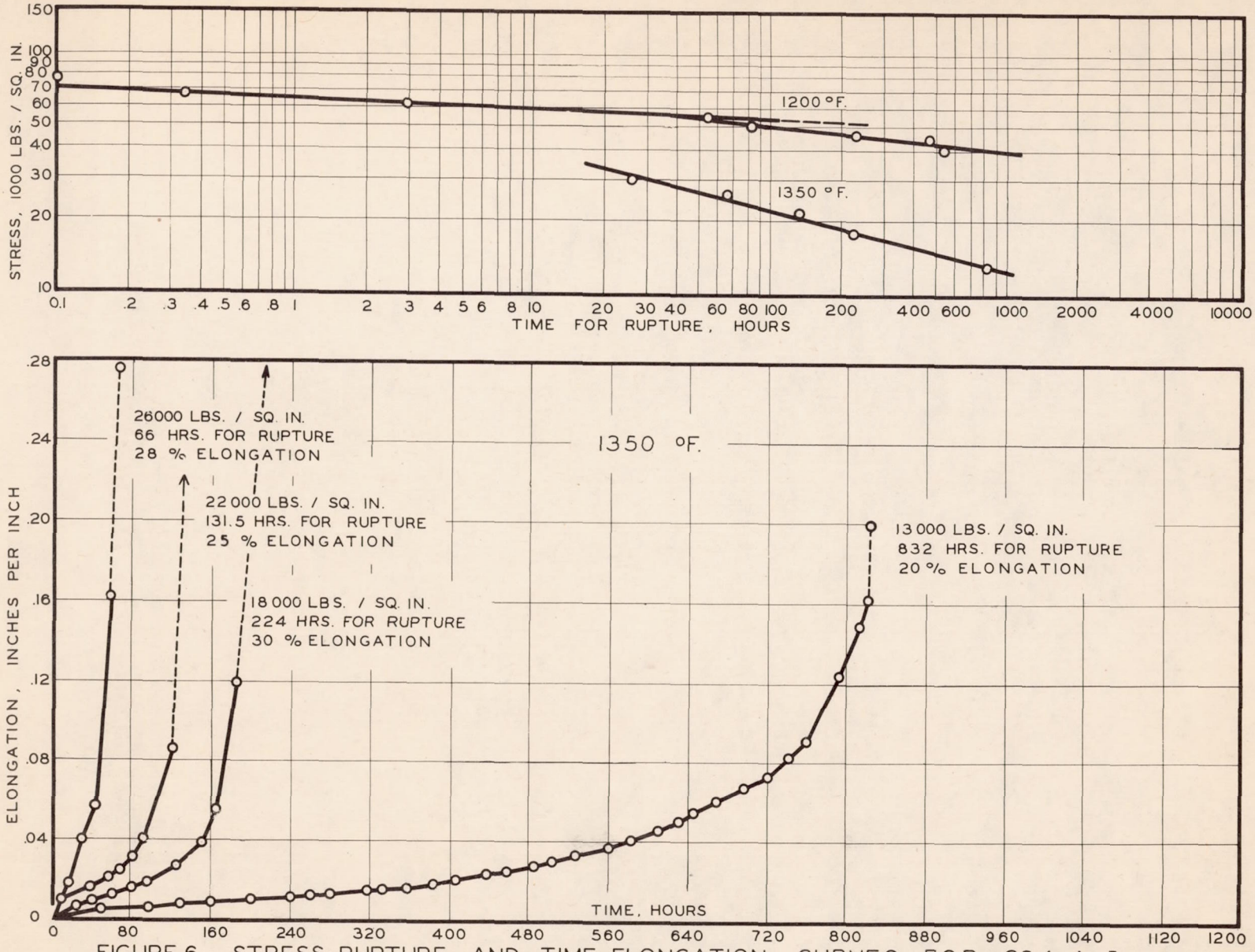


FIGURE 6 - STRESS-RUPTURE AND TIME-ELONGATION CURVES FOR 234-A-5

ALLOY Gamma Columbium - Annealed* (A8736)

MANUFACTURER Universal-Cyclops Steel Corporation

COMPOSITION 0.40% C, 0.46% Si, 0.84% Mn, 15.08% Cr, 24.71% Ni, 4.39% Mo, 1.90% Cb, 0.036 N_2

TREATMENT Melted in an electric arc furnace, 12,000 pound heat. Hammer Cogged and rolled at 2050-1860°F. to 3/4 inch square bar. Heated 1 hour at 2150°F. and air cooled.

HARDNESS 189 Brinell

TENSILE PROPERTIES

Temperature Deg. F.	Tensile Strength Lb./Sq.In.	Yield Stress Lb./Sq.In. 0.02%	Yield Stress Lb./Sq.In. 0.2%	Proportional Limit Lb./Sq.In.	Elongation % in 2 In.	Reduction of Area %
80	107,750	32,500	46,000	22,500	37.0	38.5
	108,000	31,200	45,000	22,500	37.0	46.6
1200	79,250		33,500	25,000	18.0	18.8
	81,500		32,000	20,000	19.0	17.0

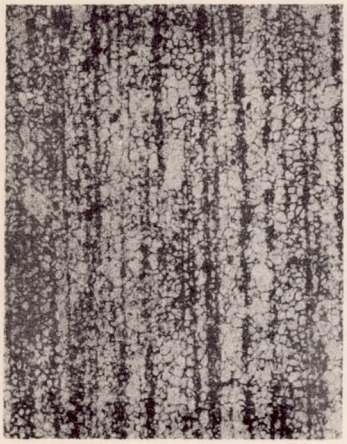
STRESS-RUPTURE DATA AT 1200° F

Stress Lb./Sq.In.	Time for Rupture Hours	Elongation % in 1 In.	Reduction of Area %
64,000	1.30	7.0	12.7
60,000	2.77	8.0	17.2
45,000	56.0	10.0	12.1
40,000	236.0	6.0	9.7
36,000	1188.0	7.0	10.8

STRESS-RUPTURE STRENGTHS AT 1200° F
(from stress-rupture time plot)

Time for Rupture Hours	Stress Lb./Sq.In.
1	66,000
10	54,000
100	44,000
1000	36,000

*Alloys Gamma Columbium-Annealed, Gamma Columbium-Hot Rolled, Gamma Columbium-Hot Worked, and Gamma Columbium-"Cold" Worked are from the same heat and differ only in processing.



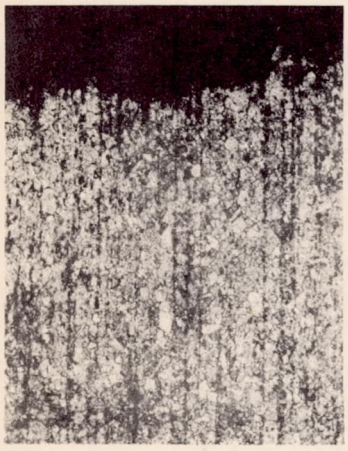
100X



1000X

As Received

Vickers Hardness - 201



Fracture - 100X



Interior - 1000X

1200°F.

36,000 Lbs. per Sq. In.
1188 Hrs. to Rupture

Vickers Hardness - 252

MICROSTRUCTURES OF GAMMA COLUMBIUM - ANNEALED
AS RECEIVED AND AFTER RUPTURE TEST AT 1200°F.

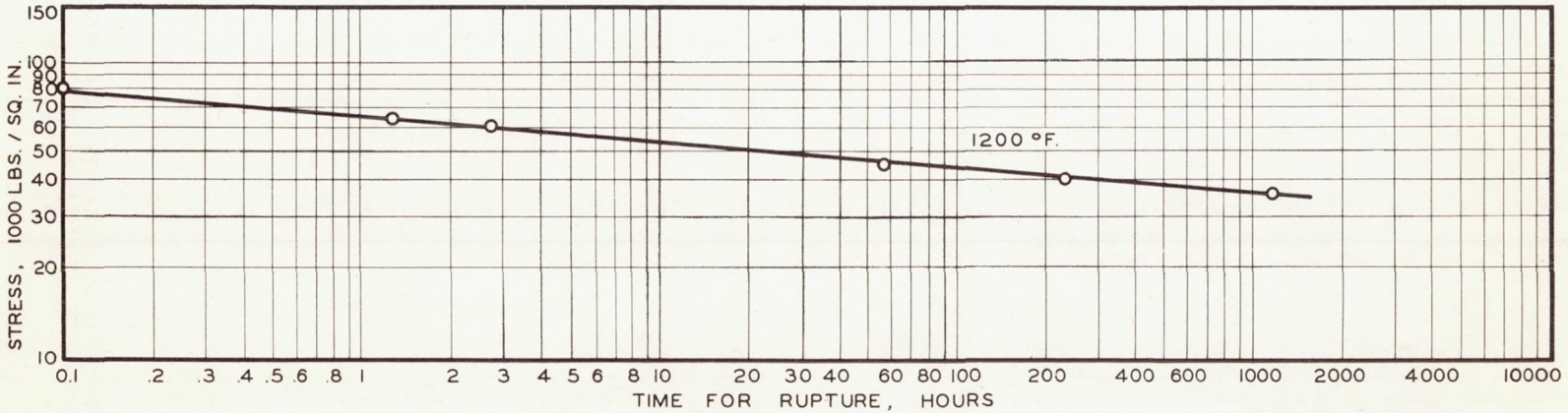


FIGURE 7 - STRESS-RUPTURE CURVE FOR ANNEALED GAMMA COLUMBIUM

ALLOY Gamma Columbium - Hot Rolled* (A8736)

MANUFACTURER Universal-Cyclops Steel Corporation

COMPOSITION 0.40% C, 0.46% Si, 0.84% Mn, 15.08% Cr, 24.71% Ni, 4.39% Mo, 1.90% Cb, 0.015% S, 0.018% P, 0.036% N_2

TREATMENT Melted in electric arc furnace, 12,000 pound heat. Ingots hammer cogged. Rolled at 2050/1860°F. to a 3/4 inch square bar. Stress relieved by soaking thru at 1200°F. and air cooled.

HARDNESS 198 Brinell

TENSILE PROPERTIES

Temperature Deg. F.	Tensile Strength Lb./Sq.In.	Yield Stress Lb./Sq.In. 0.02%	Yield Stress Lb./Sq.In. 0.2%	Proportional Limit Lb./Sq.In.	Elongation % in 2 In.	Reduction of Area %
80	111,750	38,500	52,500	25,000	34.0	33.5
	111,000	31,000	49,500	17,500	33.0	39.1
1200	79,500		36,500	22,500	16.0	20.6
	81,625		36,125	20,000	20.0	20.8

STRESS-RUPTURE DATA AT 1200° F

Stress Lb./Sq.In.	Time for Rupture Hours	Elongation % in 1 In.	Reduction of Area %
72,000	0.63	13.0	15.6
65,000	0.90	10.0	13.7
60,000	1.82	6.0	13.2
45,000	68.0	4.0	3.6
40,000	154.0	6.0	7.3
31,000	1155.0	10.0	14.5

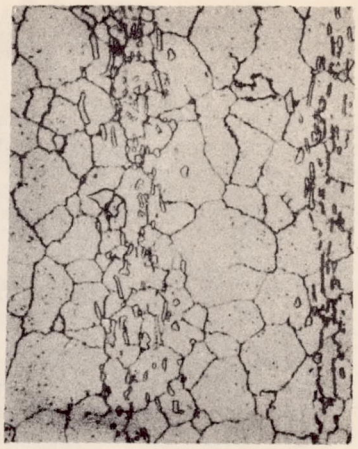
STRESS-RUPTURE STRENGTHS AT 1200° F
(from stress-rupture time plot)

Time for Rupture Hours	Stress Lb./Sq.In.
1	68,000
10	56,000
100	43,000
1000	31,400

*Alloys Gamma Columbium-Annealed, Gamma Columbium-Hot Rolled, Gamma Columbium-Hot Worked, and Gamma Columbium-"Cold" Worked are from the same heat and differ only in processing.



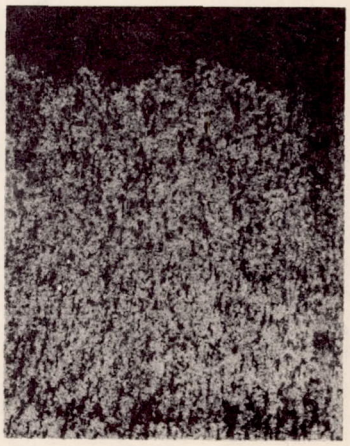
100X



1000X

As Received

Vickers Hardness - 214



Fracture - 100X



Interior - 1000X

1200°F.

31,000 Lbs. per Sq. In.
1155 Hrs. to Rupture

Vickers Hardness - 237

MICROSTRUCTURES OF GAMMA COLUMBIUM - HOT ROLLED
AS RECEIVED AND AFTER RUPTURE TEST AT 1200°F.

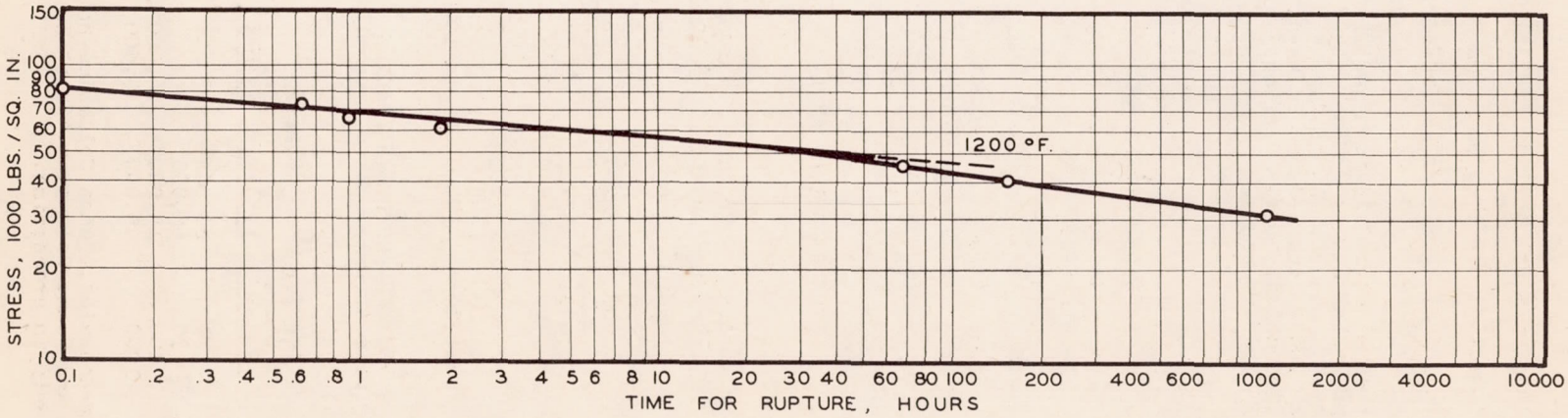


FIGURE 8 - STRESS-RUPTURE CURVE FOR HOT-ROLLED GAMMA COLUMBIUM

ALLOY Gamma Columbium - Hot Worked* (A8736)

MANUFACTURER Universal-Cyclops Steel Corporation

COMPOSITION 0.40% C, 0.46% Si, 0.84% Mn, 15.08% Cr, 24.71% Ni, 4.39% Mo, 1.90% Cb, 0.036 N_2

TREATMENT Melted in an electric arc furnace; 12,000 pound heat. Forged and rolled at 2050/1860°F. to 7/8 inch square bar. Heated 1 hour at 2100°F. and air cooled. Reheated to 1700°F. and reduced in area 22.98% by rolling and air cooled. Stress relieved by heating through at 1200°F. and air cooled.

HARDNESS 239 Brinell

TENSILE PROPERTIES

Temperature Deg. F.	Tensile Strength Lb./Sq.In.	Yield Stress Lb./Sq.In. 0.02%	Yield Stress Lb./Sq.In. 0.2%	Proportional Limit Lb./Sq.In.	Elongation % in 2 In.	Reduction of Area %
80	119,250	72,000	91,000	55,000	21.0	38.5
	118,250	71,000	90,000	57,000	20.0	37.3
1200	84,000		69,500	40,000	20.0	38.5
	81,500		70,000	37,500	21.0	41.2

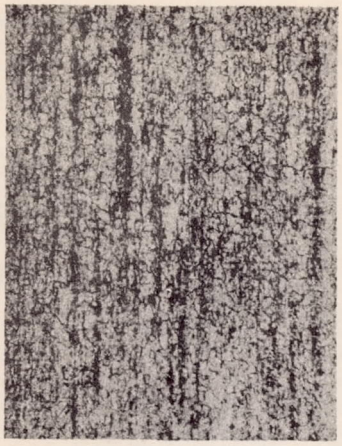
STRESS-RUPTURE DATA

Temperature Deg. F.	Stress Lb./Sq.In.	Time for Rupture Hours	Elongation % in 1 In.	Reduction of Area %
1200	75,000	0.23	20.0	41.8
	64,000	2.52	15.0	41.8
	50,000	42.0	16.0	39.8
	48,000	83.0	16.0	31.3
	44,000	271.0	15.0	38.9
	39,000	617.0	14.0	23.4
1350	32,000	17.0	32.0	40.0
	26,000	95.0	16.0	29.8
	22,000	390.0	10.0	10.9

STRESS-RUPTURE STRENGTHS
(from stress-rupture time plot)

Time for Rupture Hours	Stress Lb./Sq.In. 1200°F.	Stress Lb./Sq.In. 1350°F.
1	68,000	
10	58,000	
100	48,000	26,000
1000	38,000	19,500

*Alloys Gamma Columbium-Annealed, Gamma Columbium-Hot Rolled, Gamma Columbium-Hot Worked, and Gamma Columbium-"Cold" Worked are from the same heat and differ only in processing.



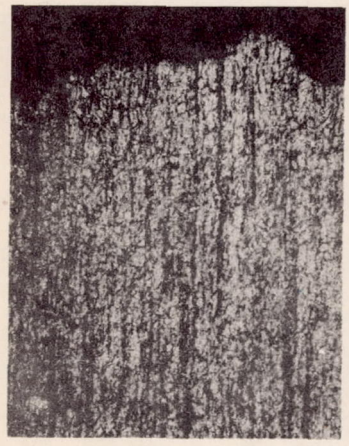
100X



1000X

As Received

Vickers Hardness - 214



Fracture - 100X

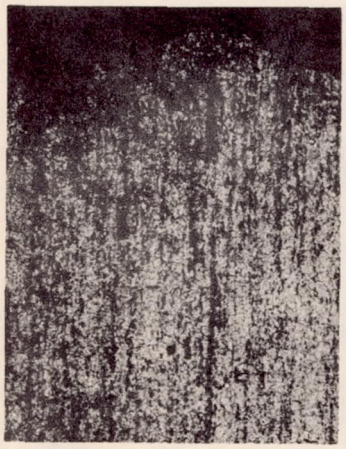


Interior - 1000X

1200°F.

39,000 Lbs. per Sq. In.
617.0 Hrs. to Rupture

Vickers Hardness - 228



Fracture - 100X



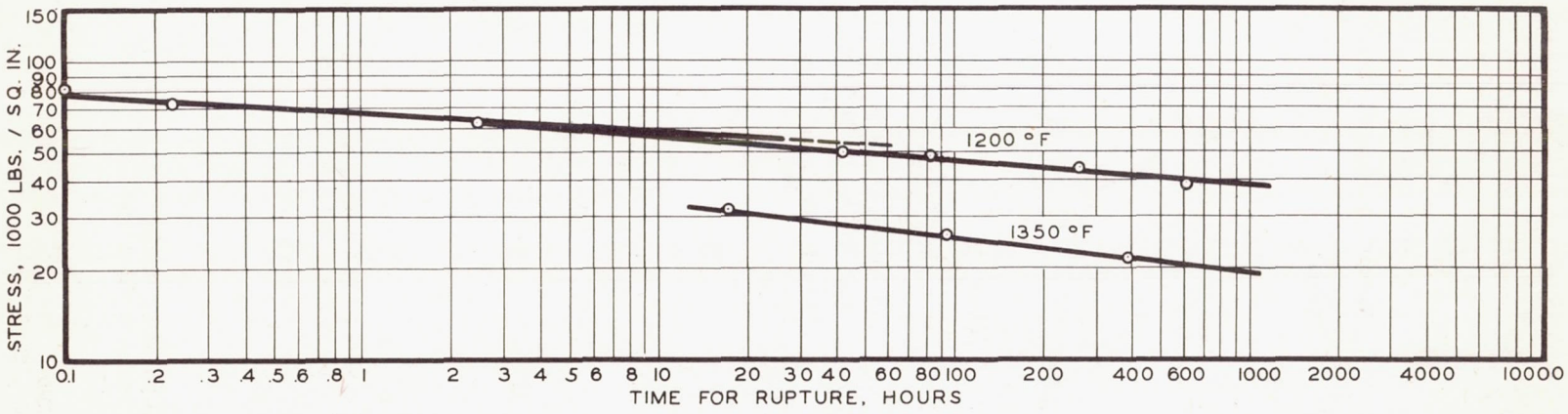
Interior - 1000X

1350°F.

22,000 Lbs. per Sq. In.
390.0 Hrs. to Rupture

Vickers Hardness - 215

MICROSTRUCTURES OF GAMMA COLUMBIUM - HOT WORKED
AS RECEIVED AND AFTER RUPTURE TESTS AT 1200°F. AND 1350°F.



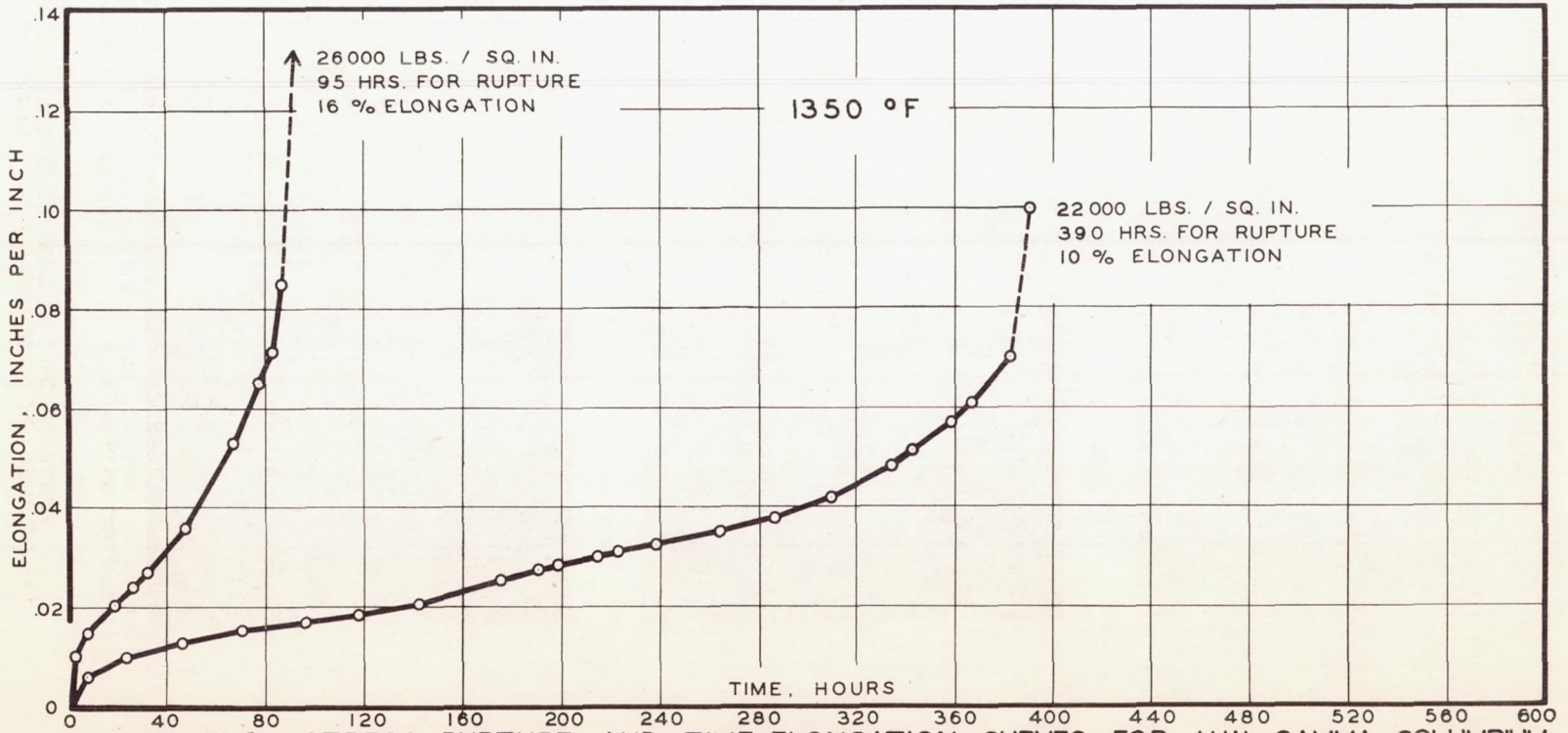


FIGURE 9 - STRESS-RUPTURE AND TIME-ELONGATION CURVES FOR H.W. GAMMA COLUMBIUM

ALLOY Gamma Columbium - "Cold" Worked* (A8736)

MANUFACTURER Universal-Cyclops Steel Corporation

COMPOSITION 0.40% C, 0.46% Si, 0.84% Mn, 15.08% Cr, 24.71% Ni, 4.39% Mo. 1.90% Cb, 0.036% N_2

TREATMENT Melted in electric arc furnace, 12,000 pound heat. Rolled at 2050/1860°F. to 7/8 inch square bar; then rolled at 1200°F. to 22.1% reduction in area. Stress relieved by soaking thru at 1200°F. and air cooled.

HARDNESS 333 Brinell

TENSILE PROPERTIES

Temperature Deg. F.	Tensile Strength Lb./Sq.In.	Yield Stress Lb./Sq.In. 0.02%	Yield Stress Lb./Sq.In. 0.2%	Proportional Limit Lb./Sq.In.	Elongation % in 2 In.	Reduction of Area %
80	160,250	115,000	146,000	75,000	12.0	28.3
	161,500	121,000	148,000	75,000	14.5	30.0
1200	110,875		100,000	47,500	6.0	10.7
	110,750		-------	------	7.0	11.8

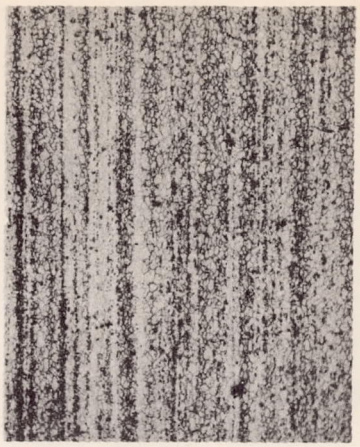
STRESS-RUPTURE DATA

Temperature Deg. F.	Stress Lb./Sq.In.	Time for Rupture Hours	Elongation % in 1 In.	Reduction of Area %
1200	93,000	1.04	4.0	7.8
	87,000	1.63	2.0	2.3
	60,000	32.2	3.0	2.3
	50,000	126.0	1.0	3.7
	40,000	612.	2.0	2.8
1350	32,000	18.0	5.0	8.3
	26,000	67.0	6.0	7.4
	20,000	198.0	8.0	6.7
	16,000	476.0	8.0	6.7

STRESS-RUPTURE STRENGTHS
(from stress-rupture time plot)

Time for Rupture Hours	Stress Lb./Sq.In. 1200°F.	Stress Lb./Sq.In. 1350°F.
1	95,000	
10	70,000	
100	51,000	23,500
1000	37,000	13,500

*Alloys Gamma Columbium-Annealed, Gamma Columbium-Hot Rolled, Gamma Columbium-Hot Worked, and Gamma Columbium-"Cold" Worked are from the same heat and differ only in processing.



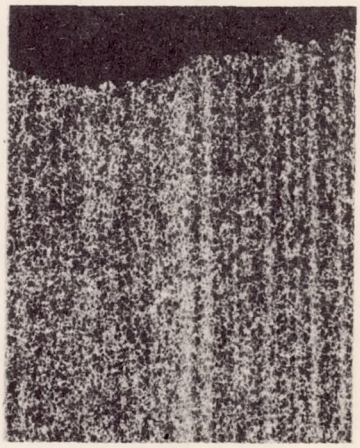
100X



1000X

As Received

Vickers Hardness - 342



Fracture - 100X

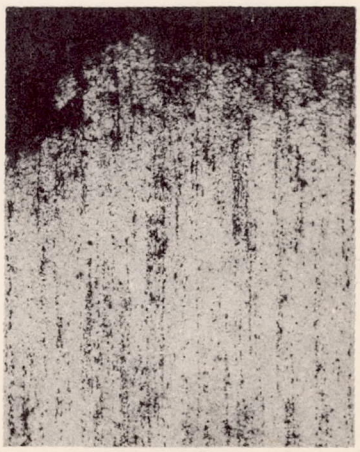


Interior - 1000X

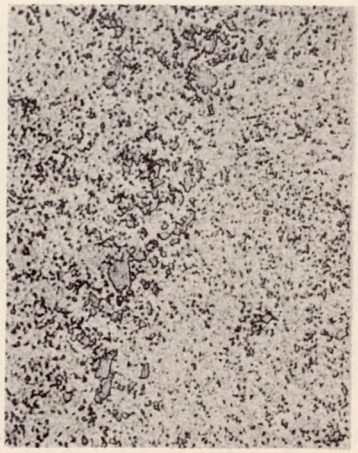
1200°F.

40,000 Lbs. per Sq. In.
612.0 Hrs. to Rupture

Vickers Hardness - 300



Fracture - 100X



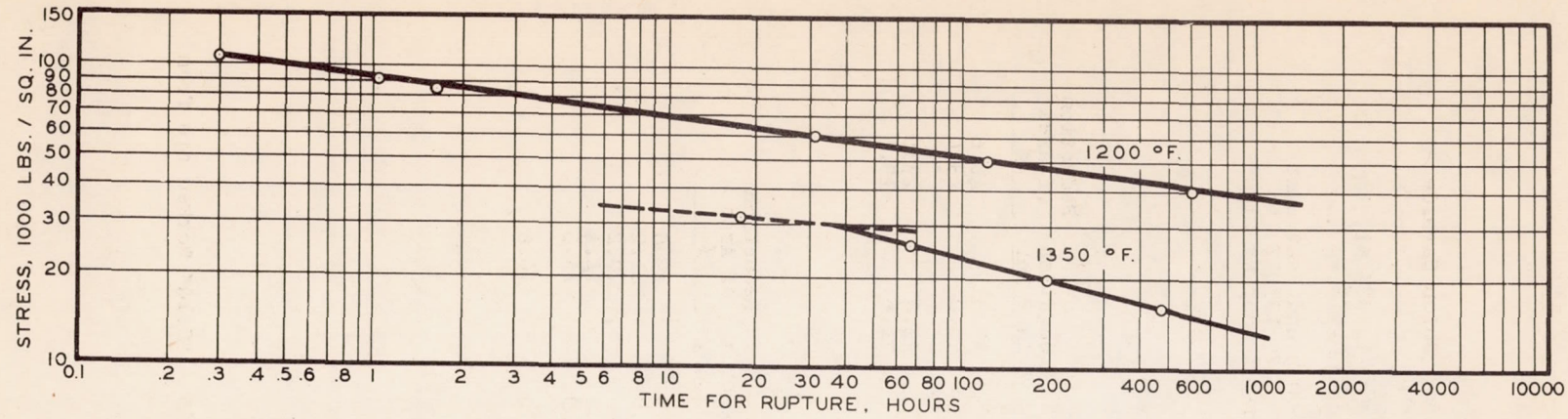
Interior - 1000X

1350°F.

16,000 Lbs. per Sq. In.
475.0 Hrs. to Rupture

Vickers Hardness - 263

MICROSTRUCTURES OF GAMMA COLUMBIUM - COLD WORKED
AS RECEIVED AND AFTER RUPTURE TESTS AT 1200°F. AND 1350°F.



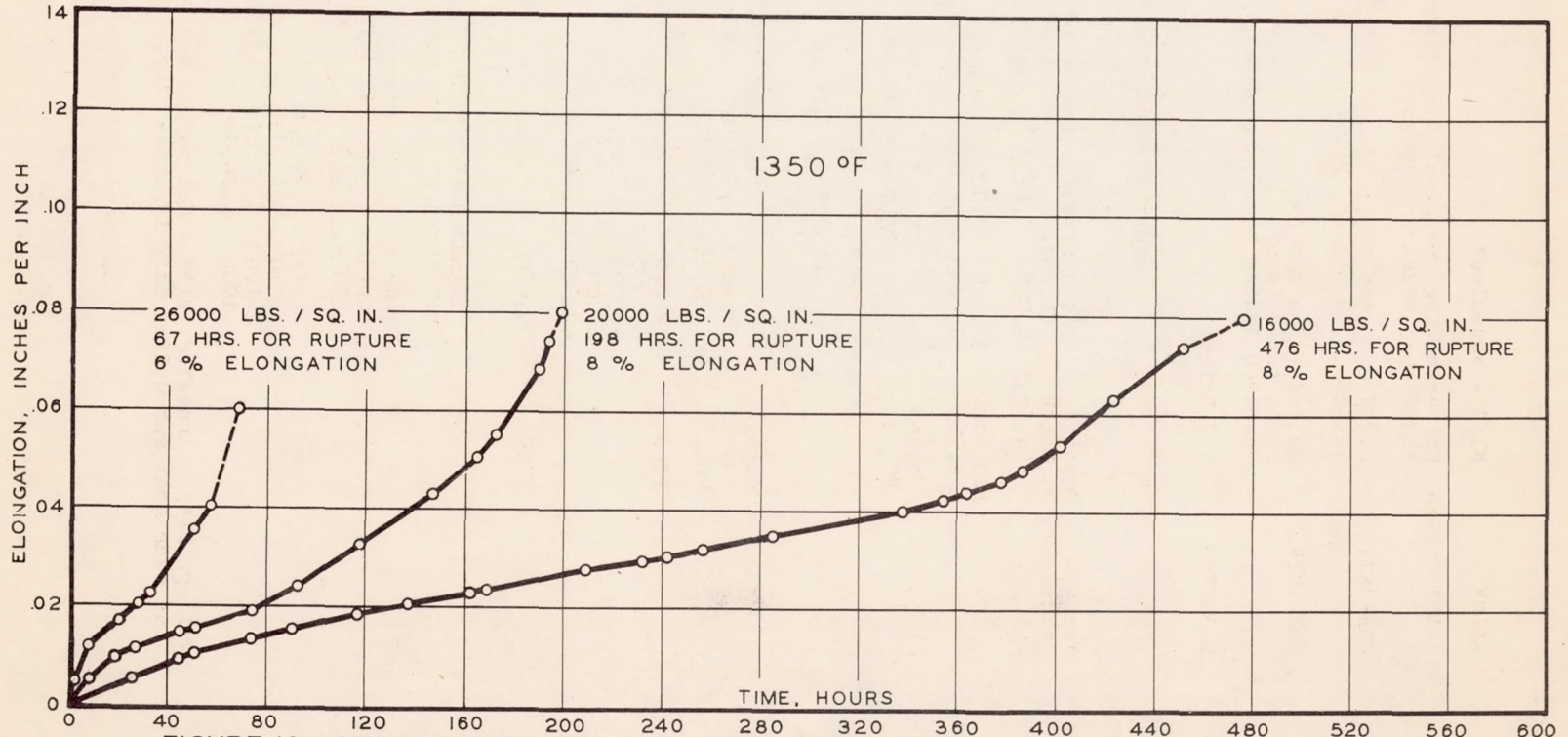


FIGURE 10- STRESS-RUPTURE AND TIME-ELONGATION CURVES FOR C.W. GAMMA COLUMBIUM

ALLOY N153 - Annealed*

MANUFACTURER Universal-Cyclops Steel Corporation and Union Carbide and Carbon Research Laboratories, Inc.

COMPOSITION 0.35% C, 0.52% Si, 1.78% Mn, 16.20% Cr, 14.98% Ni, 12.82% Co, 3.01% Mo, 2.19% W, 1.06% Cb, 0.07% N_2

TREATMENT Melted in an electric arc furnace, 600 pound heat cast in 45 pound ingot. Hammer forged at 2075/1350°F. to 3/4 inch square bar. Air cooled after 1 hour at 2100°F.

HARDNESS 207 Brinell

TENSILE PROPERTIES

Temperature Deg. F.	Tensile Strength Lb./Sq.In.	Yield Stress Lb./Sq.In. 0.02%	Yield Stress Lb./Sq.In. 0.2%	Proportional Limit Lb./Sq.In.	Elongation % in 2 In.	Reduction of Area %
80	120,000	37,500	58,000	20,000	39.0	46.6
	119,375	38,500	57,000	20,000	36.0	43.0
1200	82,500		33,000	22,500	24.0	23.0
	87,500		34,700	20,000	24.0	13.5

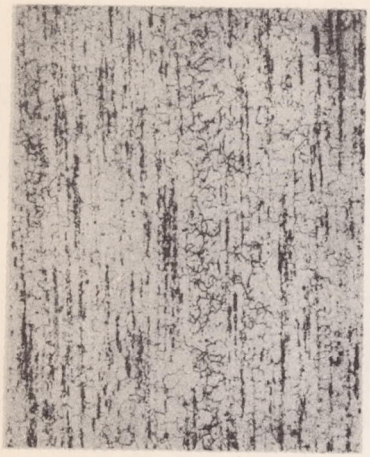
STRESS-RUPTURE DATA

Temperature Deg. F.	Stress Lb./Sq.In.	Time for Rupture Hours	Elongation % in 1 In.	Reduction of Area %
1200	78,000	0.23	18.0	19.0
	65,000	4.40	9.0	21.2
	50,000	84.5	---	20.2
	45,000	271.0	7.0	14.4
	40,000	651.0	11.0	15.6
1350	30,000	56.5	32.0	46.6

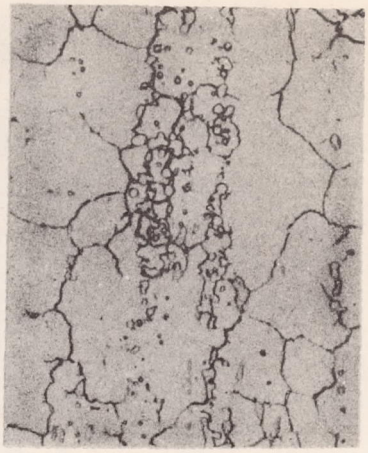
STRESS-RUPTURE STRENGTHS
(from stress-rupture time plot)

Time for Rupture Hours	Stress Lb./Sq.In. 1200°F.	Stress Lb./Sq.In. 1350°F.
1	72,000	
10	62,000	
100	50,000	28,000
1000	38,000	

*Alloys N153 - Annealed, N153 - Hot Worked and N153 - "Cold" Worked are from the same heat and differ only in processing.



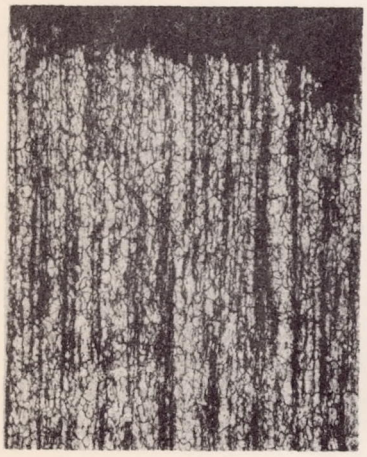
100X



1000X

As Received

Vickers Hardness - 238



Fracture - 100X



Interior - 1000X

1200°F.

40,000 Lbs. per Sq. In.
651 Hrs. to Rupture

Vickers Hardness— 263

MICROSTRUCTURES OF ALLOY N153 - ANNEALED
AS RECEIVED AND AFTER RUPTURE TEST AT 1200°F.

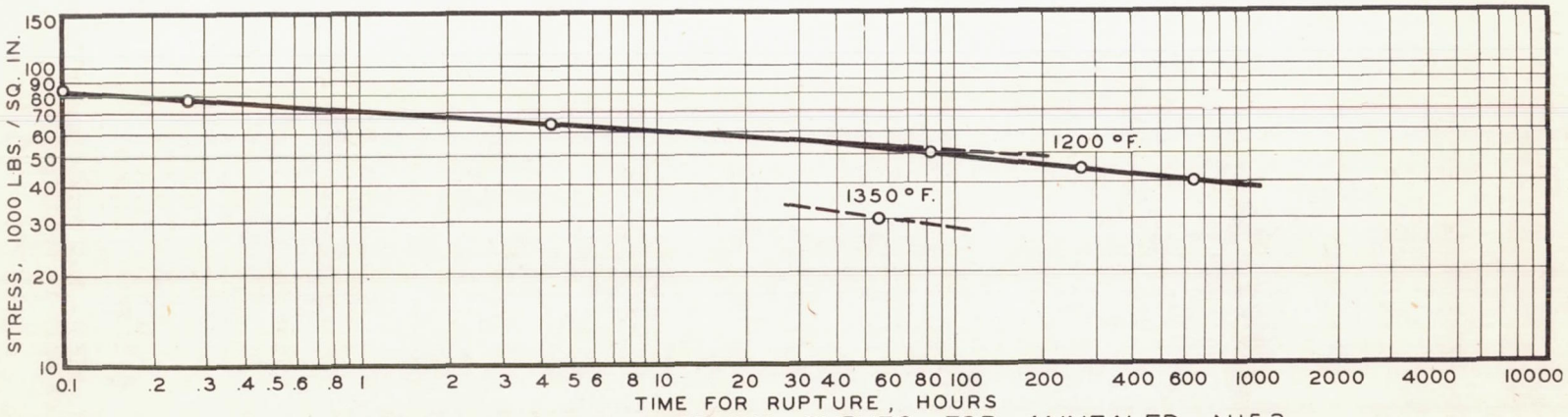


FIGURE 11 - STRESS-RUPTURE CURVES FOR ANNEALED N153

ALLOY N153 - Hot Worked*

MANUFACTURER Universal-Cyclops Steel Corporation and Union Carbide and Carbon Research Laboratories, Inc.

COMPOSITION 0.38%, 0.52% Si, 1.78% Mn, 16.20% Cr, 14.98% Ni, 12.82% Co, 3.01% Mo, 2.19% W, 1.06% Cb, 0.07% N_2

TREATMENT Melted in an electric arc furnace, 600 pound heat, cast in 45 pound ingot. Hammer forged at 2075/1600°F. to 7/8 inch square bar. Heated 1 hour at 2100°F. and air cooled. Reheated to 1700°F. and reduced in area 24.18% by rolling. Stress relieved by heating through at 1200°F. and air cooled.

HARDNESS 296 Brinell

TENSILE PROPERTIES

Temperature Deg. F.	Tensile Strength Lb./Sq.In.	Yield Stress Lb./Sq.In. 0.02%	Yield Stress Lb./Sq.In. 0.2%	Proportional Limit Lb./Sq.In.	Elongation % in 2 In.	Reduction of Area %
80	142,500	97,500	121,800	75,000	17.5	36.6
	140,750	93,000	119,000	70,000	20.0	41.6
1200	92,750		82,500	45,000	16.5	42.2
	94,000		82,500	45,000	16.5	38.2

STRESS-RUPTURE DATA

Temperature Deg. F.	Stress Lb./Sq.In.	Time for Rupture Hours	Elongation % in 1 In.	Reduction of Area %
1200	83,000	0.97	16.0	40.4
	78,000	2.97	8.0	16.1
	58,000	66.0	10.0	20.1
	50,000	161.0	16.0	25.6
	45,000	419.0	8.0	20.1
1350	32,000	35.5	20.0	36.0
	29,000	89.0	15.0	23.4
	26,000	229.0	10.0	24.5
	24,000	301.0	12.0	15.0
	20,000	661.0	8.0	12.1

STRESS-RUPTURE STRENGTHS
(from stress-rupture time plot)

Time for Rupture Hours	Stress Lb./Sq.In. 1200°F.	Stress Lb./Sq.In. 1350°F.
1	83,000	
10	73,000	
100	54,000	28,500
1000	40,000	19,000

*Alloys N153 - Annealed, N153 - Hot Worked and N153 - "Cold" Worked are from the same heat and differ only in processing.



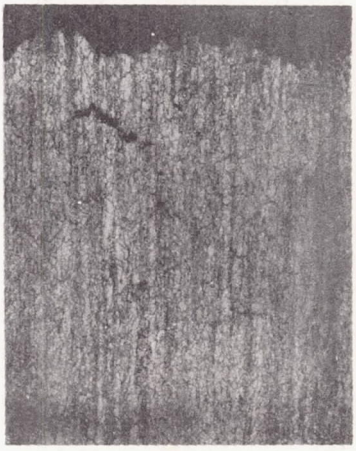
100X



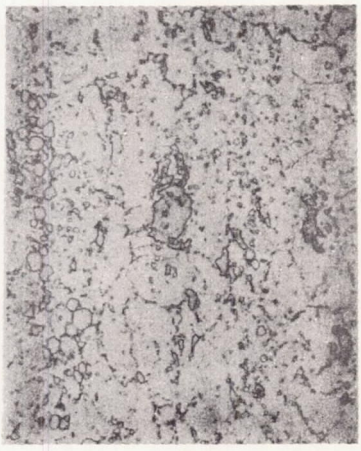
1000X

As Received

Vickers Hardness - 318



Fracture - 100X

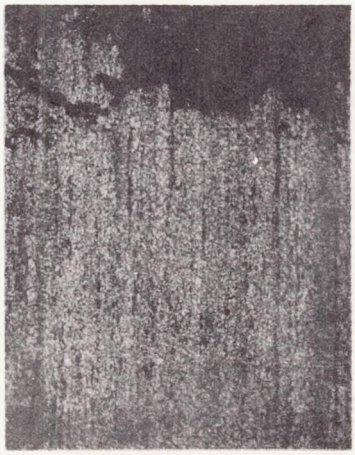


Interior - 1000X

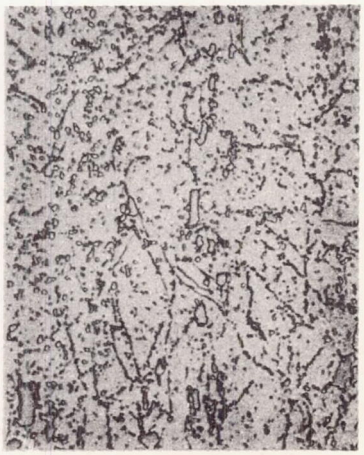
1200°F.

45,000 Lbs. per Sq. In.
419.0 Hrs. to Rupture

Vickers Hardness - 277



Fracture - 100X



Interior - 1000X

1350°F.

20,000 Lbs. per Sq. In.
661.0 Hrs. to Rupture

Vickers Hardness - 263

MICROSTRUCTURES OF ALLOY N153 - HOT WORKED
AS RECEIVED AND AFTER RUPTURE TESTS AT 1200 AND 1350°F.

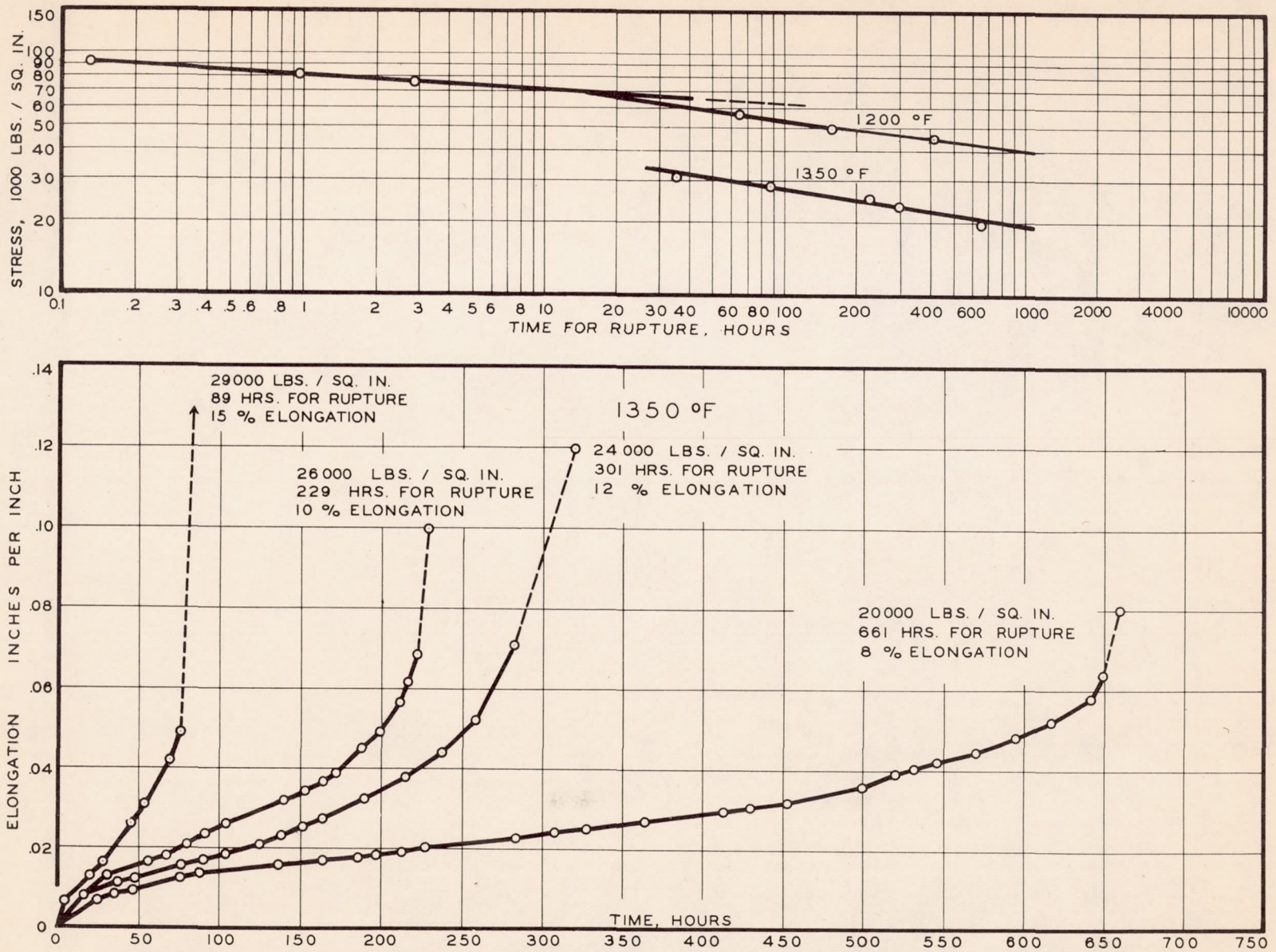


FIGURE 12-STRESS-RUPTURE AND TIME-ELONGATION CURVES FOR HOT-WORKED N153

ALLOY N153 - "Cold" Worked*

MANUFACTURER Universal-Cyclops Steel Corporation and Union Carbide and Carbon Research Laboratories, Inc.

COMPOSITION 0.38% C, 0.52% Si, 1.78% Mn, 16.20% Cr, 14.98% Ni, 12.82% Co, 3.01% Mo, 2.19% W, 1.06% Cb, .07% N_2

TREATMENT Melted in an electric arc furnace, 600 pound heat, 45 pound ingot. Hammer forged at 2075/1600°F. to 7/8 inch square bar. Heated 1 hour to 2100°F. and air cooled. Reheated to 1200°F. and reduced in area 23.15% by rolling. Stress relieved by heating through at 1200°F. and air cooled.

HARDNESS 324 Brinell

TENSILE PROPERTIES

Temperature Deg. F.	Tensile Strength Lb./Sq.In.	Yield Stress Lb./Sq.In. 0.02%	Yield Stress Lb./Sq.In. 0.2%	Proportional Limit Lb./Sq.In.	Elongation % in 2 In.	Reduction of Area %
80	157,500	117,500	141,000	100,000	18.0	36.3
	157,250	112,500	140,500	95,000	17.5	35.7
1200	110,000		95,000	57,500	13.0	31.1
	104,750		88,750	50,000	12.0	27.5

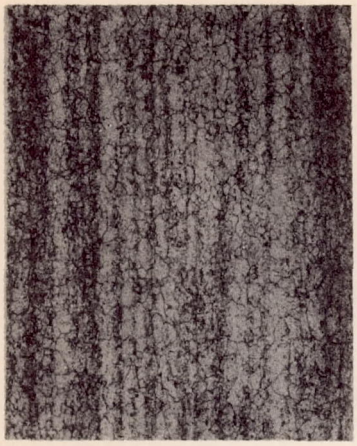
STRESS-RUPTURE DATA

Temperature Deg. F.	Stress Lb./Sq.In.	Time for Rupture Hours	Elongation % in 1 In.	Reduction of Area %
1200	90,000	0.95	4.0	13.8
	84,000	4.30	4.0	5.5
	62,000	67.0	10.0	14.3
	54,000	216.0	5.0	9.7
	45,000	723.0	4.0	10.9
1350	36,000	37.0	5.0	11.1
	32,000	232.0	3.0	7.3
	30,000	60.0	6.0	5.5
	29,000	161.0	5.0	4.9
	28,000	279.0	4.0	4.9

STRESS-RUPTURE STRENGTHS
(from stress-rupture time plot)

Time for Rupture Hours	Stress Lb./Sq.In. 1200°F.	Stress Lb./Sq.In. 1350°F.
1	90,000	
10	80,000	
100	60,000	31,000
1000	43,000	24,000

*Alloys N153 - Annealed, N153 - Hot Worked and N153 - "Cold" Worked are from the same heat and differ only in processing.



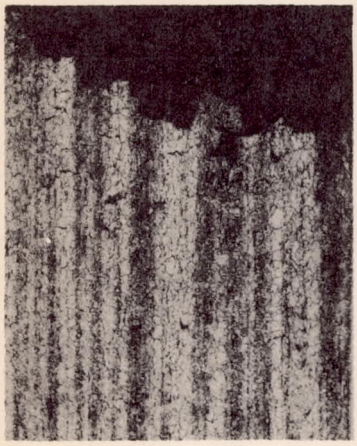
100X



1000X

As Received

Vickers Hardness - 329



Fracture - 100X

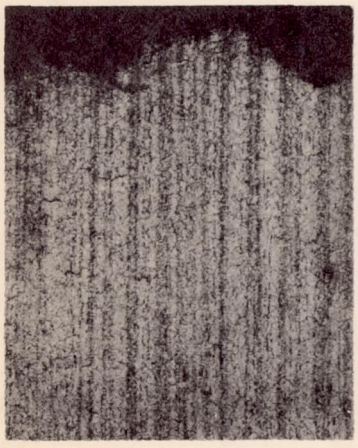


Interior - 1000X

1200°F.

45,000 Lbs. per Sq. In.
723.0 Hrs. to Rupture

Vickers Hardness - 313



Fracture - 100X



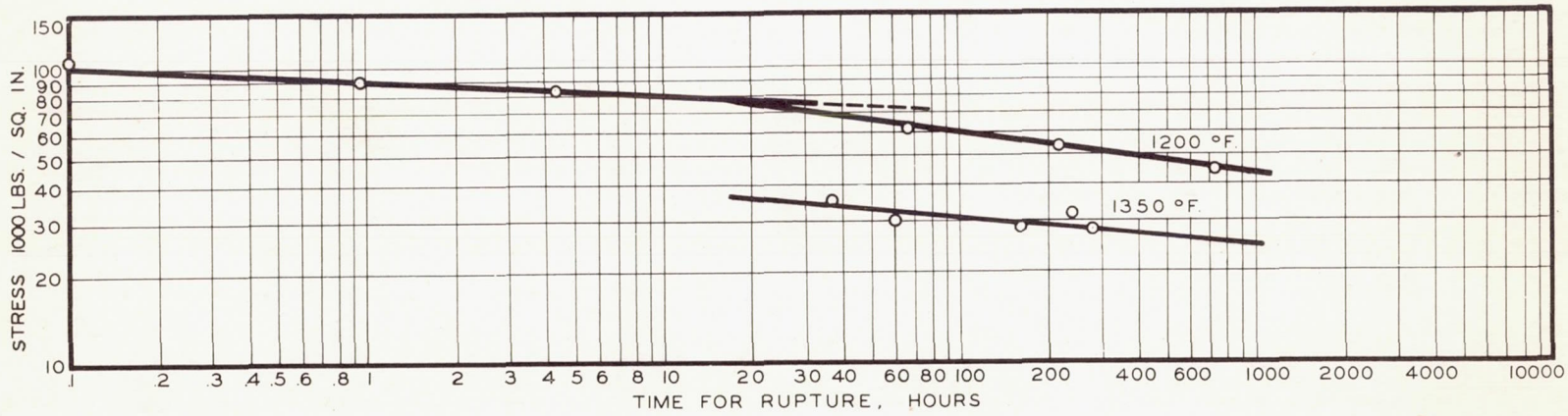
Interior - 1000X

1350°F.

28,000 Lbs. per Sq. In.
278.0 Hrs. to Rupture

Vickers Hardness - 280

MICROSTRUCTURES OF ALLOY N153 - COLD WORKED
AS RECEIVED AND AFTER RUPTURE TESTS AT 1200 AND 1350°F.



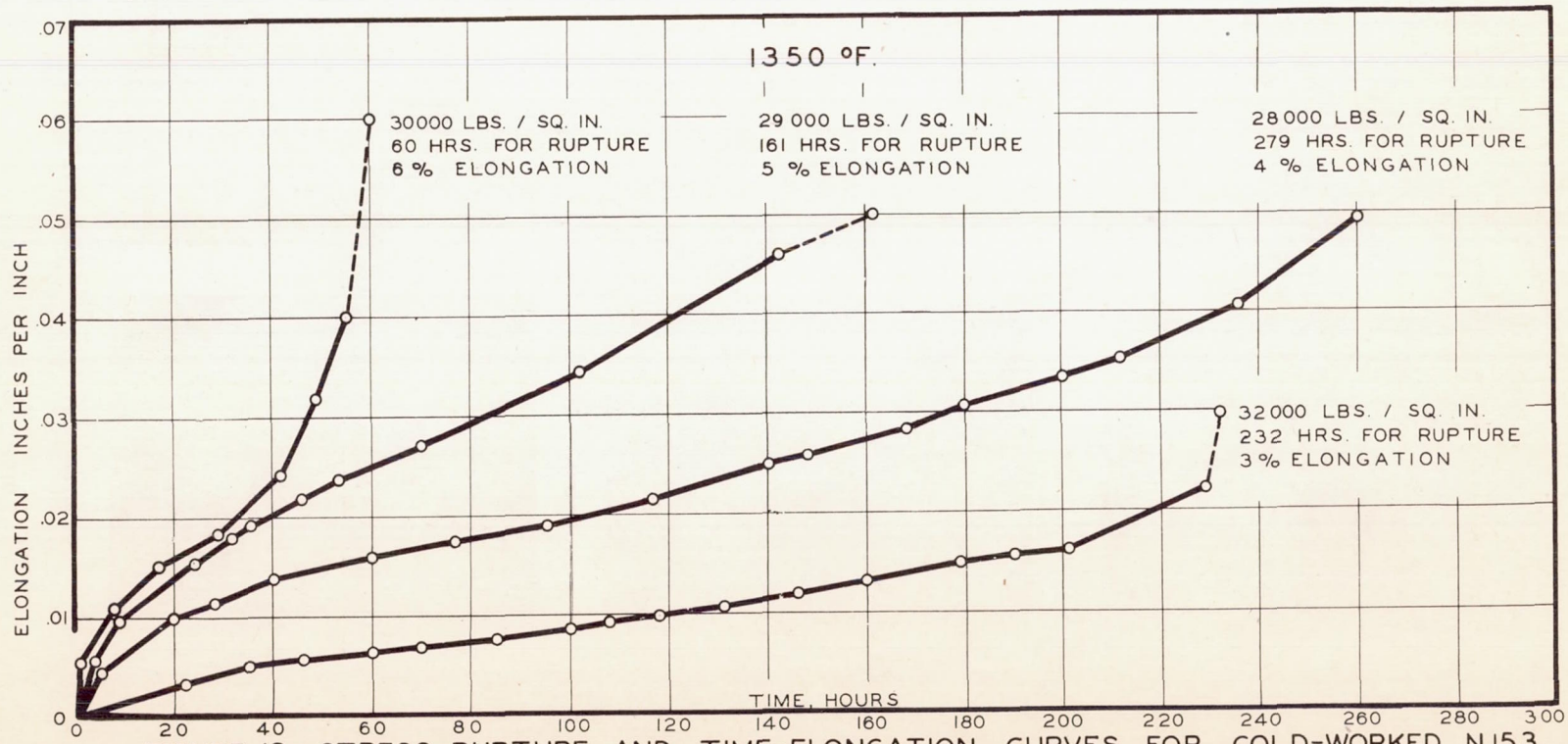


FIGURE 13- STRESS-RUPTURE AND TIME-ELONGATION CURVES FOR COLD-WORKED N153

ALLOY N154 - Annealed*

MANUFACTURER Universal-Cyclops Steel Corporation and Union Carbide and Carbon Research Laboratories, Inc.

COMPOSITION 0.32% C, 0.61% Si, 1.58% Mn, 16.17% Cr, 23.95% Ni, 20.95% Co, 3.06% Mo, 2.20% W, 1.03% Cb, 0.07% N_2

TREATMENT Melted in an electric arc furnace, 600 pound heat, cast in 45 pound ingot. Hammer forged at 2075-1340°F. to 3/4 inch square bar. Heated 1 hour at 2100°F. and air cooled.

HARDNESS 209 Brinell

TENSILE PROPERTIES

Temperature Deg. F.	Tensile Strength Lb./Sq.In.	Yield Stress Lb./Sq.In. 0.02%	Yield Stress Lb./Sq.In. 0.2%	Proportional Limit Lb./Sq.In.	Elongation % in 2 In.	Reduction of Area %
80	120,000	36,000	57,000	17,500	35.0	40.5
	119,000	38,200	54,500	17,500	36.5	44.1
1200	87,000		39,600	12,500	18.0	20.8
	89,000		41,500	20,000	21.0	21.5

STRESS-RUPTURE DATA

Temperature Deg. F.	Stress Lb./Sq.In.	Time for Rupture Hours	Elongation % in 1 In.	Reduction of Area %
1200	80,000	0.18	16.0	18.9
	70,000	1.35	11.0	16.7
	50,000	92.5	12.0	18.4
	40,000	320.0	12.0	20.0
	35,000	1061.0	12.0	21.2
1350	32,000	13.5	26.0	32.9

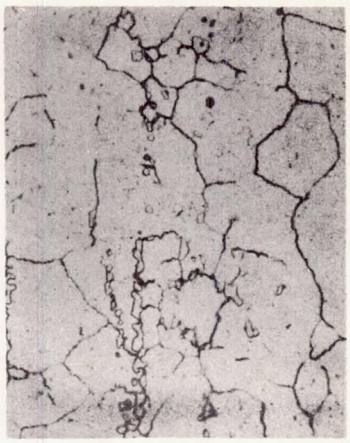
STRESS-RUPTURE STRENGTHS AT 1200° F
(from stress-rupture time plot)

Time for Rupture Hours	Stress Lb./Sq.In.
1	72,000
10	62,000
100	48,000
1000	35,000

*Alloys N154-Annealed, N154-Hot Worked and N154-"Cold" Worked are from the same heat and differ only in processing.



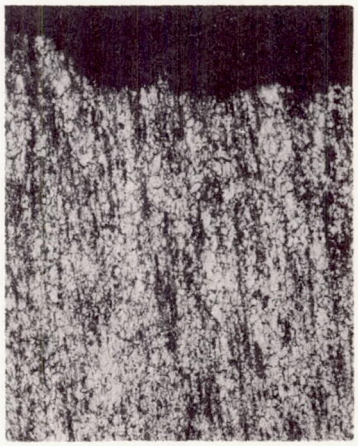
100X



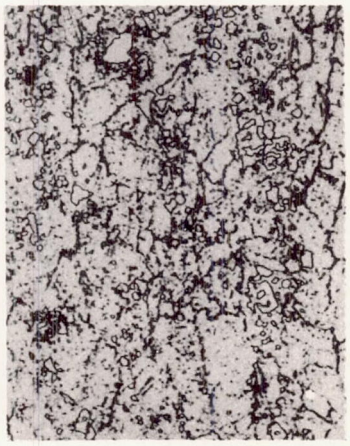
1000X

As Received

Vickers Hardness - 238



Fracture - 100X



Interior - 1000X

1200°F.

35,000 Lbs. per Sq. In.
1061 Hrs. to Rupture

Vickers Hardness - 259

MICROSTRUCTURES OF ALLOY N154 - ANNEALED
AS RECEIVED AND AFTER RUPTURE TEST AT 1200°F.

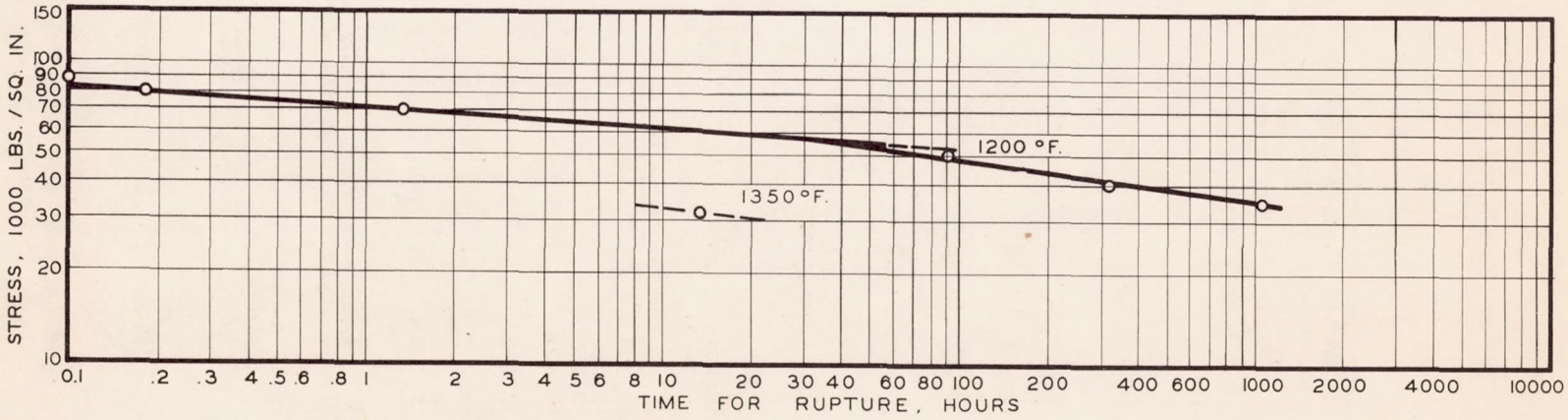


FIGURE 14- STRESS-RUPTURE CURVES FOR ANNEALED N154

ALLOY N154 - Hot Worked*

MANUFACTURER Universal-Cyclops Steel Corporation and Union Carbide and Carbon Research Laboratories, Inc.

COMPOSITION 0.32% C, 0.65% Si, 1.58% Mn, 16.17% Cr, 23.95% Ni, 20.95% Co, 3.06% Mo, 2.20% W, 1.03% Cb, 0.07% N_2

TREATMENT Melted in an electric arc furnace, 600 pound heat, cast in 45 pound ingot. Hammer forged at 2075/1600°F. to 7/8 inch square bars. Heated 1 hour at 2100°F. and air cooled. Reheated to 1700°F. and reduced in area 26.32% by rolling. Stress relieved by heating through at 1200°F. and air cooled.

HARDNESS 298 Brinell

TENSILE PROPERTIES

Temperature Deg. F.	Tensile Strength Lb./Sq.In.	Yield Stress Lb./Sq.In. 0.02%	Yield Stress Lb./Sq.In. 0.2%	Proportional Limit Lb./Sq.In.	Elongation % in 2 In.	Reduction of Area %
80	144,000	98,750	122,000	77,500	17.0	31.5
	145,000	107,000	123,750	85,000	17.5	32.8
1200	98,500		85,000	47,500	15.0	31.5
	101,000		90,000	45,000	16.0	31.1

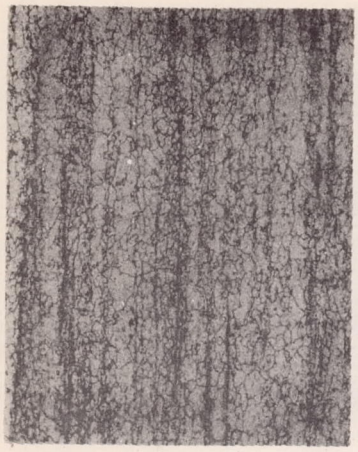
STRESS-RUPTURE DATA

Temperature Deg. F.	Stress Lb./Sq.In.	Time for Rupture Hours	Elongation % in 1 In.	Reduction of Area %
1200	88,000	0.53	12.0	23.4
	82,000	1.12	14.0	29.1
	58,000	57.0	20.0	30.8
	52,000	140.0	17.0	21.3
	45,000	835.0	9.0	20.1
1350	32,000	10.0	15.0	31.9
	30,000	74.0	17.0	22.3
	28,000	108.5	12.0	14.4
	26,000	155.0	10.0	12.1
	22,000	414.0	8.0	10.9

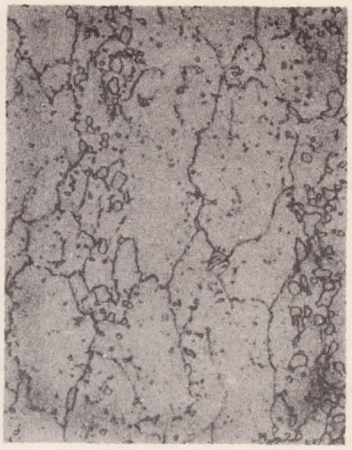
STRESS-RUPTURE STRENGTHS
(from stress-rupture time plot)

Time for Rupture Hours	Stress Lb./Sq.In. 1200°F.	Stress Lb./Sq.In. 1350°F.
1	83,000	
10	68,000	
100	54,000	28,000
1000	44,000	19,000

*Alloys N154-Annealed, N154-Hot Worked and N154-"Cold" Worked are from the same heat and differ only in processing.



100X



1000X

As Received

Vickers Hardness - 297



Fracture - 100X



Interior - 1000X

1200°F.

45,000 Lbs. per Sq. In.
835.0 Hrs. to Rupture

Vickers Hardness - 277



Fracture - 100X



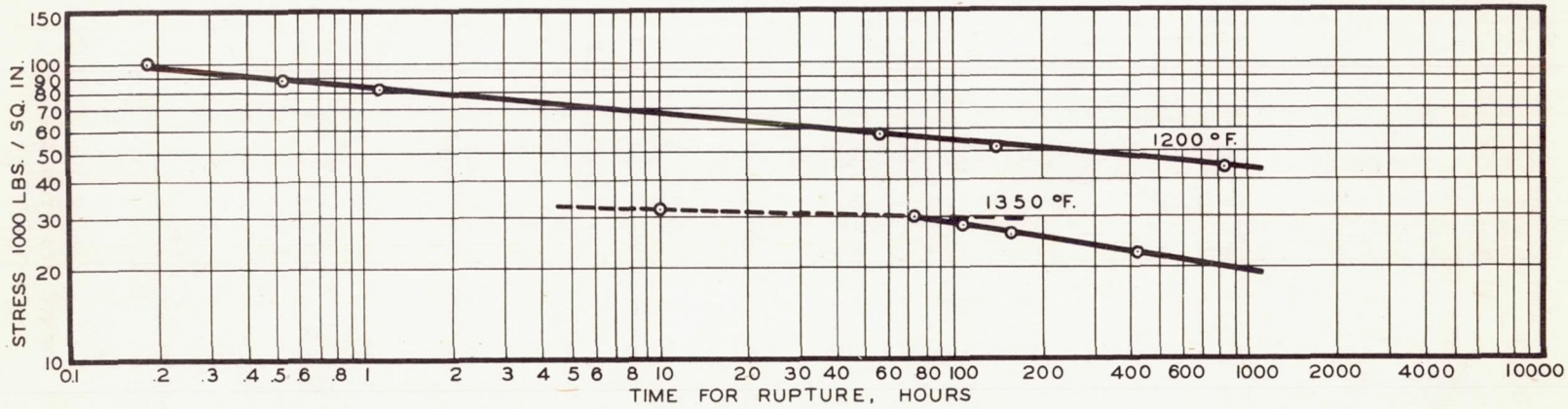
Interior - 1000X

1350°F.

22,000 Lbs. per Sq. In.
414.0 Hrs. to Rupture

Vickers Hardness - 263

MICROSTRUCTURES OF ALLOY N154 - HOT WORKED
AS RECEIVED AND AFTER RUPTURE TESTS AT 1200 AND 1350°F.



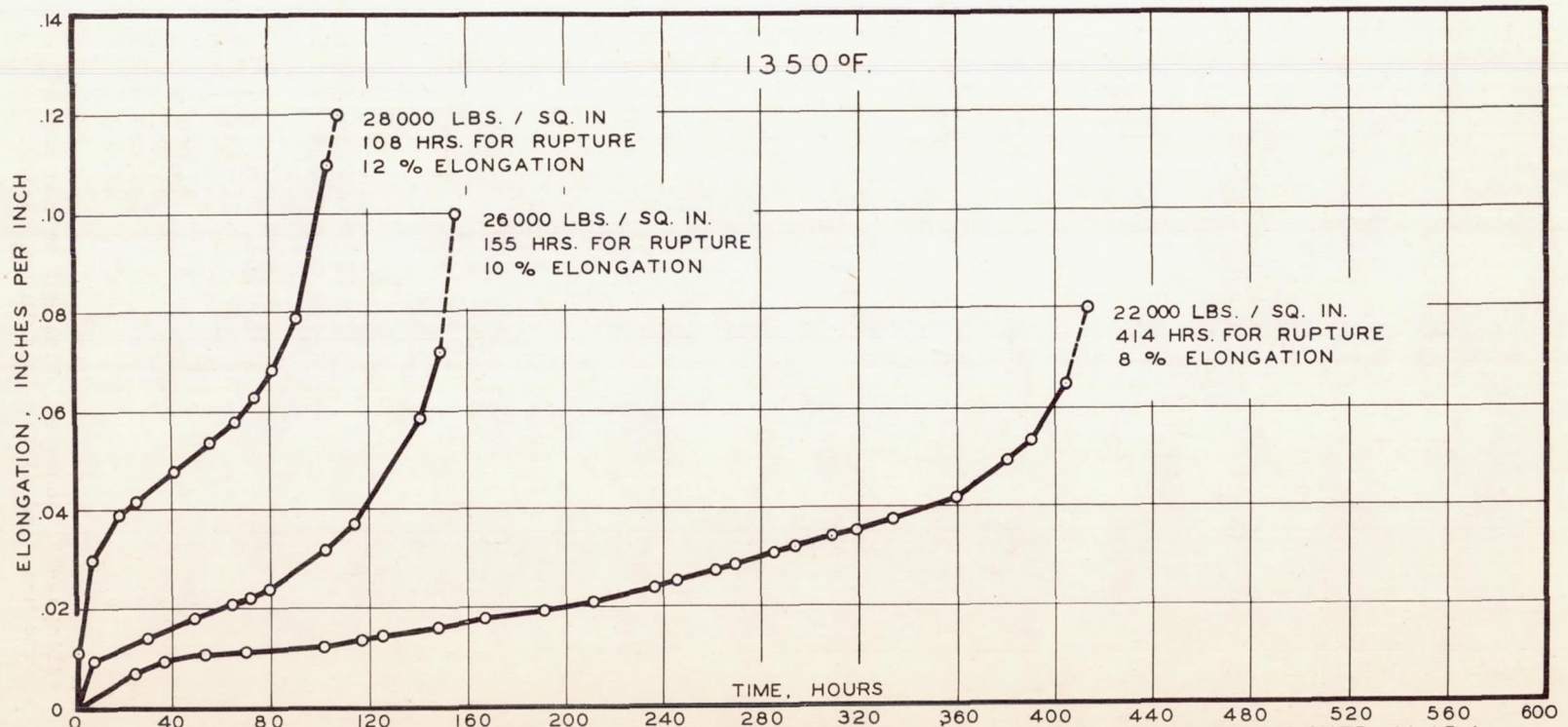


FIGURE 15 - STRESS-RUPTURE AND TIME-ELONGATION CURVES FOR HOT-WORKED N 154

ALLOY N154 - "Cold" Worked*

MANUFACTURER Universal-Cyclops Steel Corporation and Union Carbide and Carbon Research Laboratories, Inc.

COMPOSITION 0.32% C, 0.65% Si, 1.58% Mn, 16.17% Cr, 23.95% Ni, 20.95% Co, 3.06% Mo, 2.20% W, 1.03% Cb, 0.07% N_2

TREATMENT Melted in an electric arc furnace, 600 pound heat, cast in 45 pound ingot. Hammer forged at 2075/1600°F. to 7/8 inch square bars. Heated 1 hour at 2100°F. and air cooled. Reheated to 1200°F. and reduced in area 25.88% by rolling. Stress relieved by heating through at 1200°F. and air cooled.

HARDNESS 331 Brinell

TENSILE PROPERTIES

Temperature Deg. F.	Tensile Strength Lb./Sq.In.	Yield Stress Lb./Sq.In. 0.02%	Yield Stress Lb./Sq.In. 0.2%	Proportional Limit Lb./Sq.In.	Elongation % in 2 In.	Reduction of Area %
80	164,000	124,000	147,500	105,000	14.0	29.1
	164,500	136,500	163,000	105,000	13.0	28.8
1200	110,500		98,000	55,000	11.5	25.8
	117,500		102,800	47,500	10.5	30.2

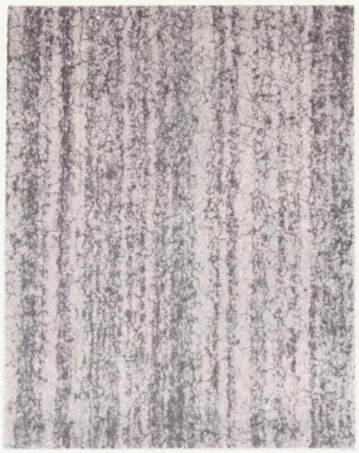
STRESS-RUPTURE DATA

Temperature Deg. F.	Stress Lb./Sq.In.	Time for Rupture Hours	Elongation % in 1 In.	Reduction of Area %
1200	95,000	0.92	10.0	22.3
	86,000	2.43	8.0	16.7
	58,000	102.0	4.0	7.3
	52,000	164.0	4.0	7.3
	45,000	573.0	4.0	8.6
1350	34,000	28.0	7.0	13.2
	30,000	84.5	7.0	10.9
	26,000	321.0	3.0	5.0
	23,000	256.5	5.0	4.3

STRESS-RUPTURE STRENGTHS
(from stress-rupture time plot)

Time for Rupture Hours	Stress Lb./Sq.In. 1200°F.	Stress Lb./Sq.In. 1350°F.
1	94,000	
10	74,000	
100	58,000	28,500
1000	42,000	20,000

*Alloys N154-Annealed, N154-Hot Worked and N154-"Cold" Worked are from the same heat and differ only in processing.



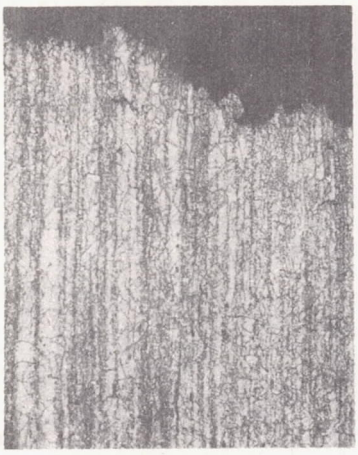
100X



1000X

As Received

Vickers Hardness - 321



Fracture - 100X

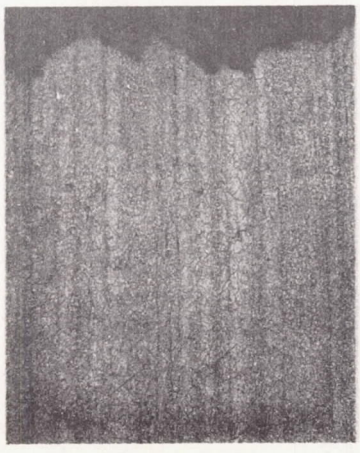


Interior - 1000X

1200°F.

45,000 Lbs. per Sq. In.
573.0 Hrs. to Rupture

Vickers Hardness - 289



Fracture - 100X



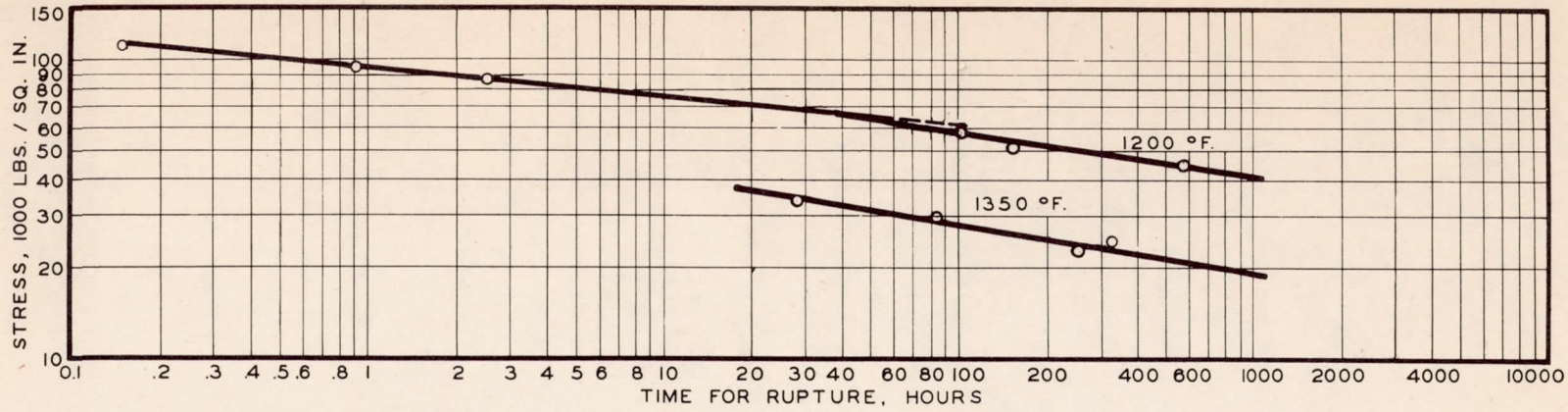
Interior - 1000X

1350°F.

26,000 Lbs. per Sq. In.
302.0 Hrs. to Rupture

Vickers Hardness - 270

MICROSTRUCTURES OF ALLOY N154 - COLD WORKED
AS RECEIVED AND AFTER RUPTURE TESTS AT 1200 AND 1350°F.



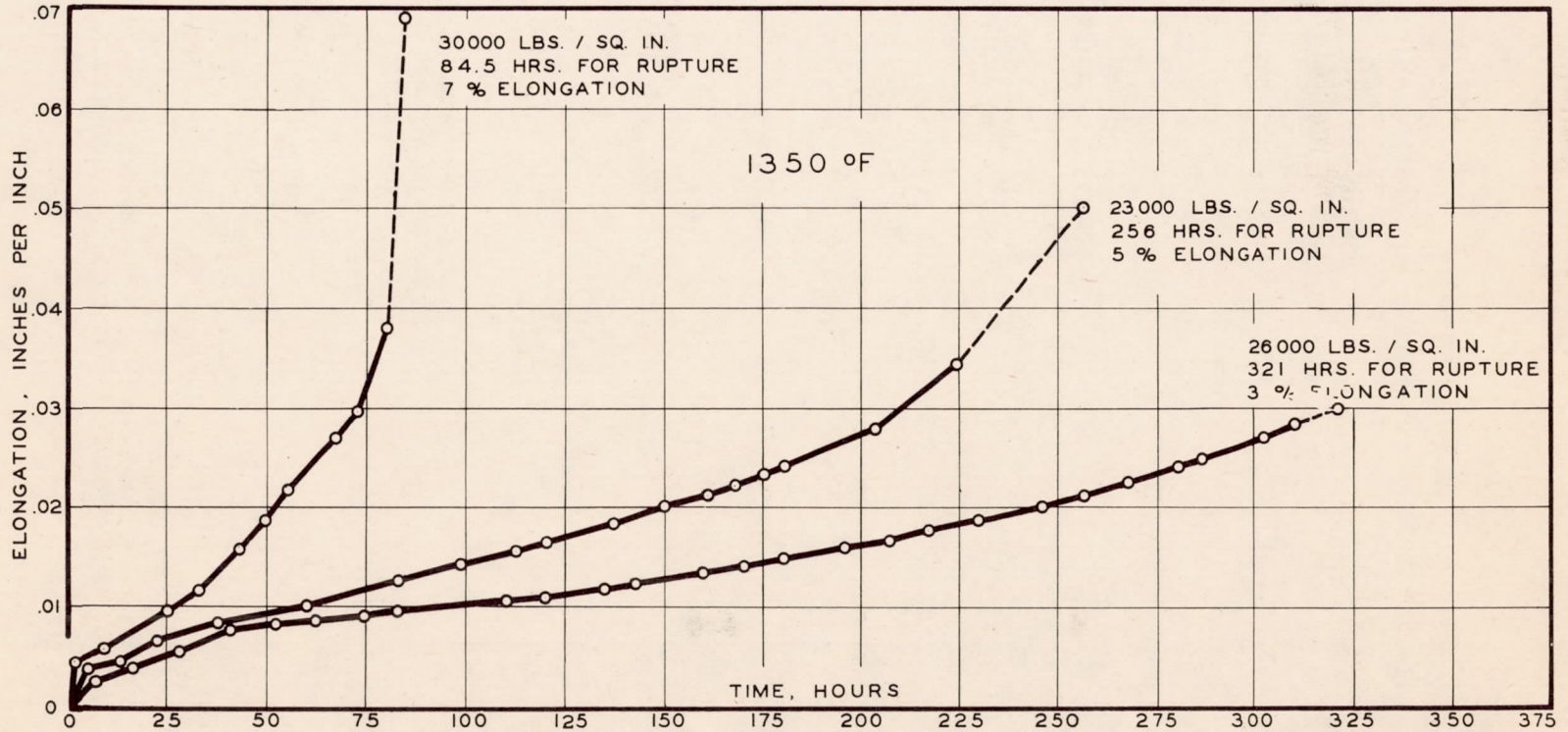


FIGURE 16 - STRESS-RUPTURE AND TIME-ELONGATION CURVES FOR COLD-WORKED N154

ALLOY	N155 - Annealed*
MANUFACTURER	Universal-Cyclops Steel Corporation and Union Carbide and Carbon Research Laboratories, Inc.
COMPOSITION	0.32% C, 0.59% Si, 1.54% Mn, 21.08% Cr, 20.80% Ni, 20.54% Co, 3.00% Mo, 2.18% W, 0.98% Cb, 0.11% N_2
TREATMENT	Melted in an electric arc furnace, 600 pound heat, cast in 45 pound ingot. Hammer forged at 2075/1320°F. to 3/4 inch square bar. Heated 1 hour at 2100°F. and air cooled.
HARDNESS	220 Brinell

TENSILE PROPERTIES

Temperature Deg. F.	Tensile Strength Lb./Sq.In.	Yield Stress Lb./Sq.In. 0.02%	Yield Stress Lb./Sq.In. 0.2%	Proportional Limit Lb./Sq.In.	Elongation % in 2 In.	Reduction of Area %
80	127,500	37,000	63,500	25,000	37.0	37.5
	128,000	40,500	63,000	20,000	35.0	38.0
1200	87,000		42,600	22,500	18.0	16.9
	87,250		42,300	30,000	15.0	18.0

STRESS-RUPTURE DATA AT 1200° F

Stress Lb./Sq.In.	Time for Rupture Hours	Elongation % in 1 In.	Reduction of Area %
77,000	0.57	15.0	20.5
70,000	1.72	12.0	13.2
50,000	157.0	10.0	17.2
45,000	308.0	15.0	18.9
40,000	828.0	18.0	22.3

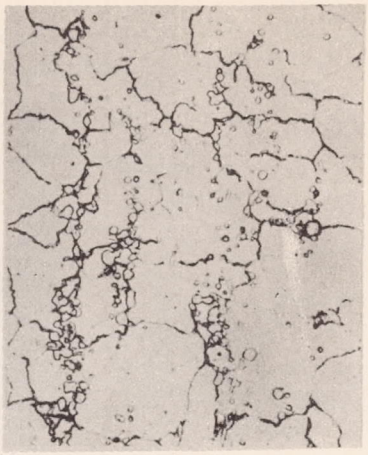
STRESS-RUPTURE STRENGTHS AT 1200° F
(from stress-rupture time plot)

Time for Rupture Hours	Stress Lb./Sq.In.
1	74,000
10	64,000
100	52,000
1000	39,000

*Alloys N155-Annealed, N155-Hot Worked and N155-"Cold" Worked are from the same heat and differ only in processing.



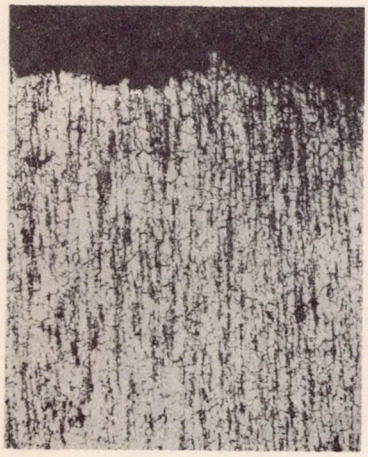
100X



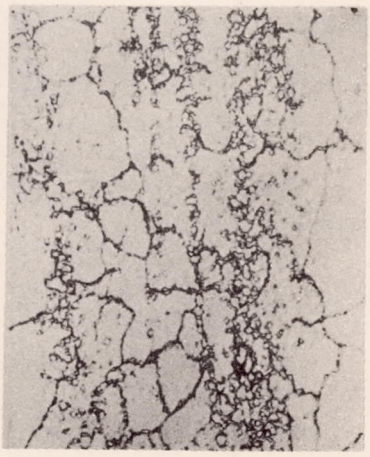
1000X

As Received

Vickers Hardness - 242



Fracture - 100X



Interior - 1000X

1200°F.

40,000 Lb. per Sq. In.
828 Hrs. to Rupture

Vickers Hardness - 285

MICROSTRUCTURES OF ALLOY N155 - ANNEALED
AS RECEIVED AND AFTER RUPTURE TEST AT 1200°F.

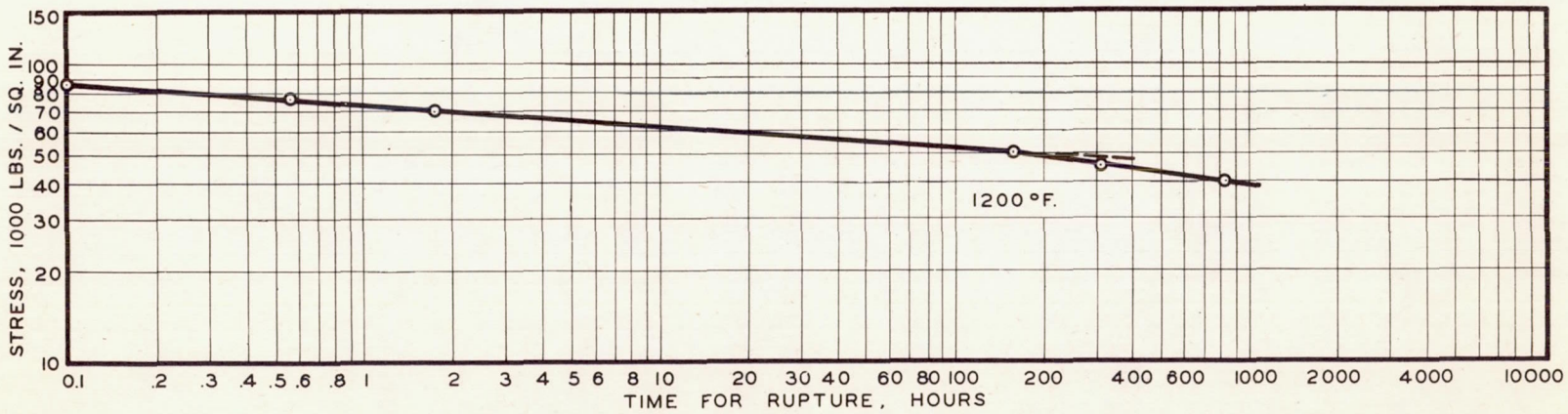


FIGURE 17- STRESS-RUPTURE CURVES FOR ANNEALED N155

ALLOY N155 - Hot Worked*

MANUFACTURER Universal-Cyclops Steel Corporation and Union Carbide and Carbon Research Laboratories, Inc.

COMPOSITION 0.32% C, 0.59% Si, 1.54% Mn, 21.08% Cr, 20.80% Ni, 20.54% Co, 3.00% Mo, 2.18% W, 0.98% Cb, 0.11% N_2

TREATMENT Melted in an electric arc furnace, 600 pound heat, cast in 45 pound ingot. Hammer forged at 2075/1600°F. to 7/8 inch square bar. Heated 1 hour at 2100°F. and air cooled. Reheated to 1700°F. and reduced in area 21.73% by rolling. Stress relieved by heating through at 1200°F. and air cooled.

HARDNESS 334 Brinell

TENSILE PROPERTIES

Temperature Deg. F.	Tensile Strength Lb./Sq.In.	Yield Stress Lb./Sq.In. 0.02%	Yield Stress Lb./Sq.In. 0.2%	Proportional Limit Lb./Sq.In.	Elongation % in 2 In.	Reduction of Area %
80	158,000	110,500	135,000	90,000	16.0	28.5
	160,500	108,000	138,500	85,000	17.0	28.8
1200	107,500		92,500	47,500	15.0	30.8
	106,500		93,750	52,500	15.0	28.5

STRESS-RUPTURE DATA

Temperature Deg. F.	Stress Lb./Sq.In.	Time for Rupture Hours	Elongation % in 1 In.	Reduction of Area %
1200	90,000	1.00	10.0	34.0
	84,000	3.27	14.0	29.8
	62,000	74.0	12.0	22.3
	54,000	212.0	8.0	12.1
	50,000	426.5	6.0	10.9
	45,000	1295.	4.0	10.9
1350	32,000	53.5	10.0	15.0
	26,000	268.0	6.0	7.3
	22,000	444.0	6.0	4.9

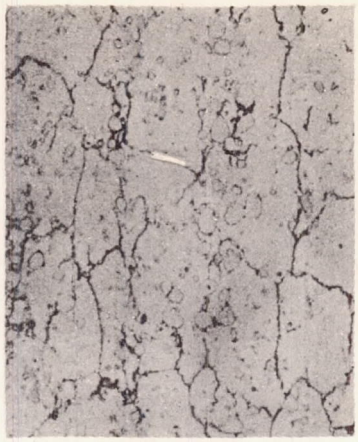
STRESS-RUPTURE STRENGTHS
(from stress-rupture time plot)

Time for Rupture Hours	Stress Lb./Sq.In. 1200°F.	Stress Lb./Sq.In. 1350°F.
1	90,000	
10	76,000	
100	59,000	28,000
1000	46,000	20,000

*Alloys N155-Annealed, N155-Hot Worked and N155-"Cold" Worked are from the same heat and differ only in processing.



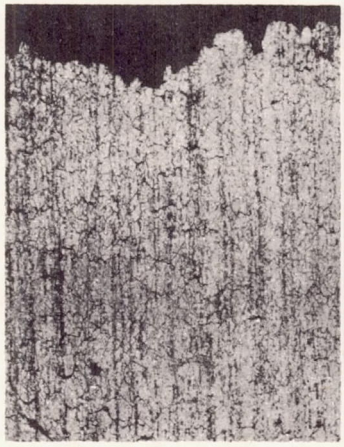
100X



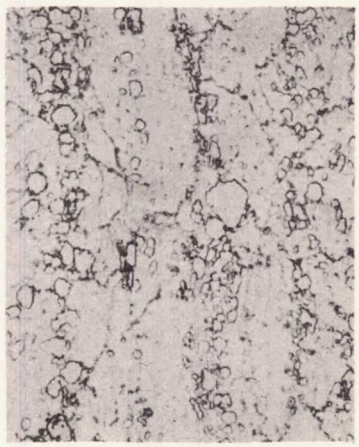
1000X

As Received

Vickers Hardness - 336



Fracture - 100X

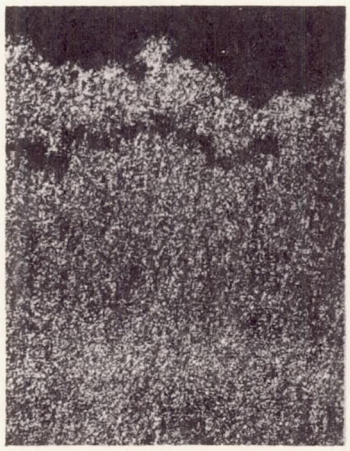


Interior - 1000X

1200°F.

45,000 Lbs. per Sq. In.
1295.0 Hrs. to Rupture

Vickers Hardness - 311



Fracture - 100X



Interior - 1000X

1350°F.

22,000 Lbs. per Sq. In.
444.0 Hrs. to Rupture

Vickers Hardness - 265

MICROSTRUCTURES OF ALLOY N155 - HOT WORKED
AS RECEIVED AND AFTER RUPTURE TESTS AT 1200 AND 1350°F.

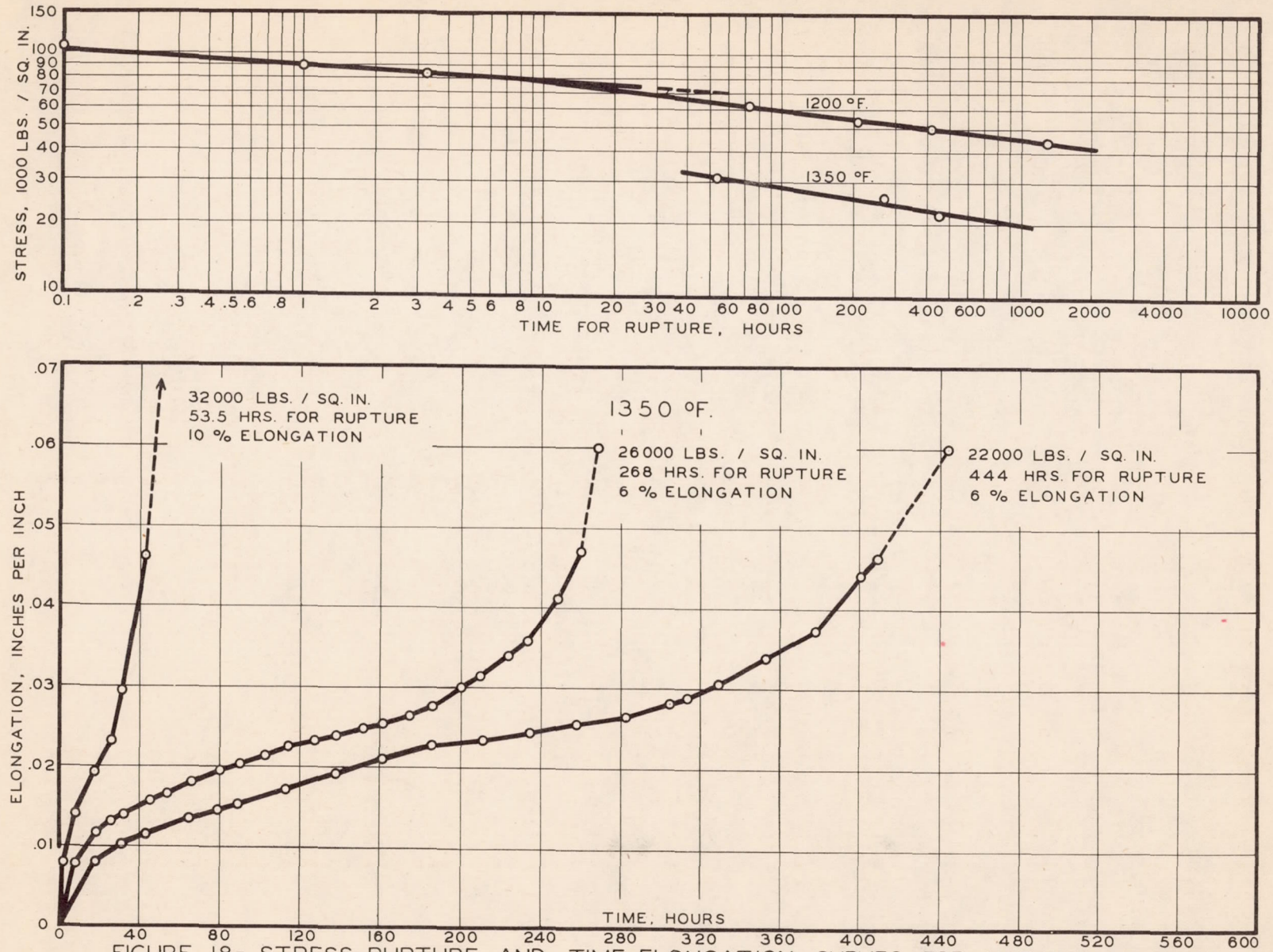


FIGURE 18- STRESS-RUPTURE AND TIME-ELONGATION CURVES FOR HOT-WORKED N155

ALLOY N155 - "Cold" Worked*

MANUFACTURER Universal-Cyclops Steel Corporation and Union Carbide and Carbon Research Laboratories, Inc.

COMPOSITION 0.32% C, 0.59% Si, 1.54% Mn, 21.08% Cr, 20.80% Ni, 20.54% Co, 3.00% Mo, 2.18% W, 0.98% Cb, 0.11% N_2

TREATMENT Melted in an electric arc furnace, 600 pound heat, cast in 45 pound ingot. Hammer forged at 2075/1600°F. to 7/8 inch square bar. Heated 1 hour at 2100°F. and air cooled. Reheated to 1200°F. and reduced in area 25.62% by rolling. Stress relieved by heating through at 1200°F. and air cooled.

HARDNESS 349 Brinell

TENSILE PROPERTIES

Temperature Deg. F.	Tensile Strength Lb./Sq.In.	Yield Stress Lb./Sq.In. 0.02%	Yield Stress Lb./Sq.In. 0.2%	Proportional Limit Lb./Sq.In.	Elongation % in 2 In.	Reduction of Area %
80	167,000	125,000	150,500	105,000	13.0	29.8
	169,500	125,000	152,500	102,500	14.0	30.8
1200	117,000		98,750	52,500	12.0	24.8
	118,750		95,000	47,500	11.0	26.5

STRESS-RUPTURE DATA

Temperature Deg. F.	Stress Lb./Sq.In.	Time for Rupture Hours	Elongation % in 1 In.	Reduction of Area %
1200	98,000	.88	8.0	13.3
	88,000	3.32	6.0	6.2
	62,000	130.0	4.0	6.2
	56,000	443.0	4.0	8.5
	54,000	202.5	2.0	1.3
	50,000	352.5	5.0	3.7
	45,000	1249.0	2.0	9.7
1350	35,000	53.0	7.0	3.8
	32,000	70.5	6.0	9.7
	29,000	62.0	6.0	4.9
	26,000	201.0	7.0	4.9
	24,000	388.5	3.0	2.4

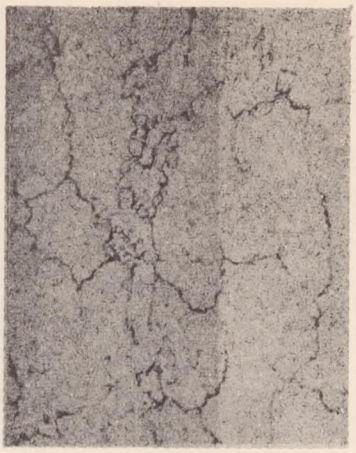
STRESS-RUPTURE STRENGTHS
(From stress-rupture time plot)

Time for Rupture Hours	Stress Lb./Sq.In. 1200°F.	Stress Lb./Sq.In. 1350°F.
1	99,000	
10	80,000	
100	63,000	30,000
1000	46,000	19,500

*Alloys N155-Annealed, N155-Hot Worked and N155-"Cold" Worked are from the same heat and differ only in processing.



100X



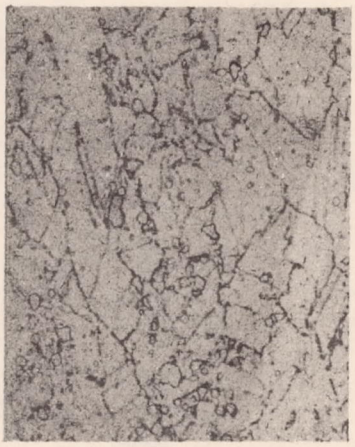
1000X

As Received

Vickers Hardness - 341



Fracture - 100X

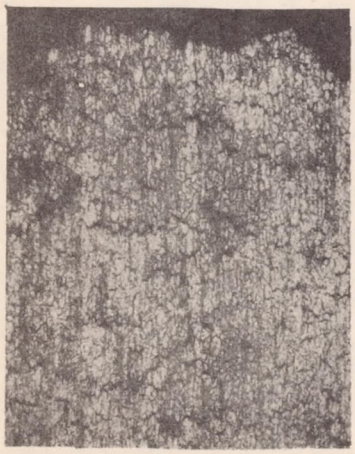


Interior - 1000X

1200°F.

45,000 Lbs. per Sq. In.
1249.0 Hrs. to Rupture

Vickers Hardness - 310



Fracture - 100X



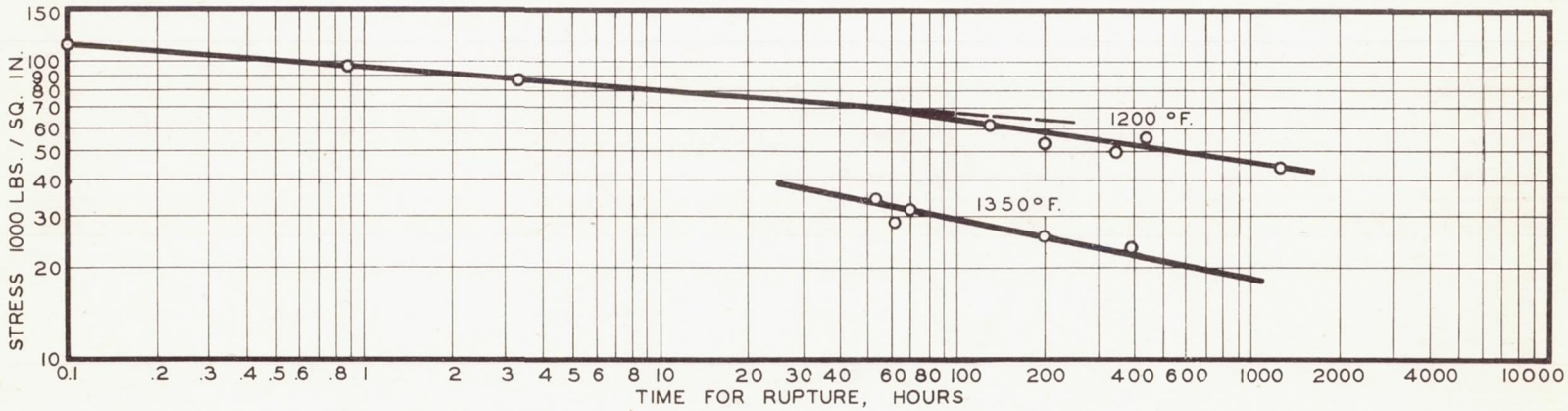
Interior - 1000X

1350°F.

24,000 Lbs. per Sq. In.
388.5 Hrs. to Rupture

Vickers Hardness - 298

MICROSTRUCTURES OF ALLOY N155 - COLD WORKED
AS RECEIVED AND AFTER RUPTURE TESTS AT 1200 AND 1350°F.



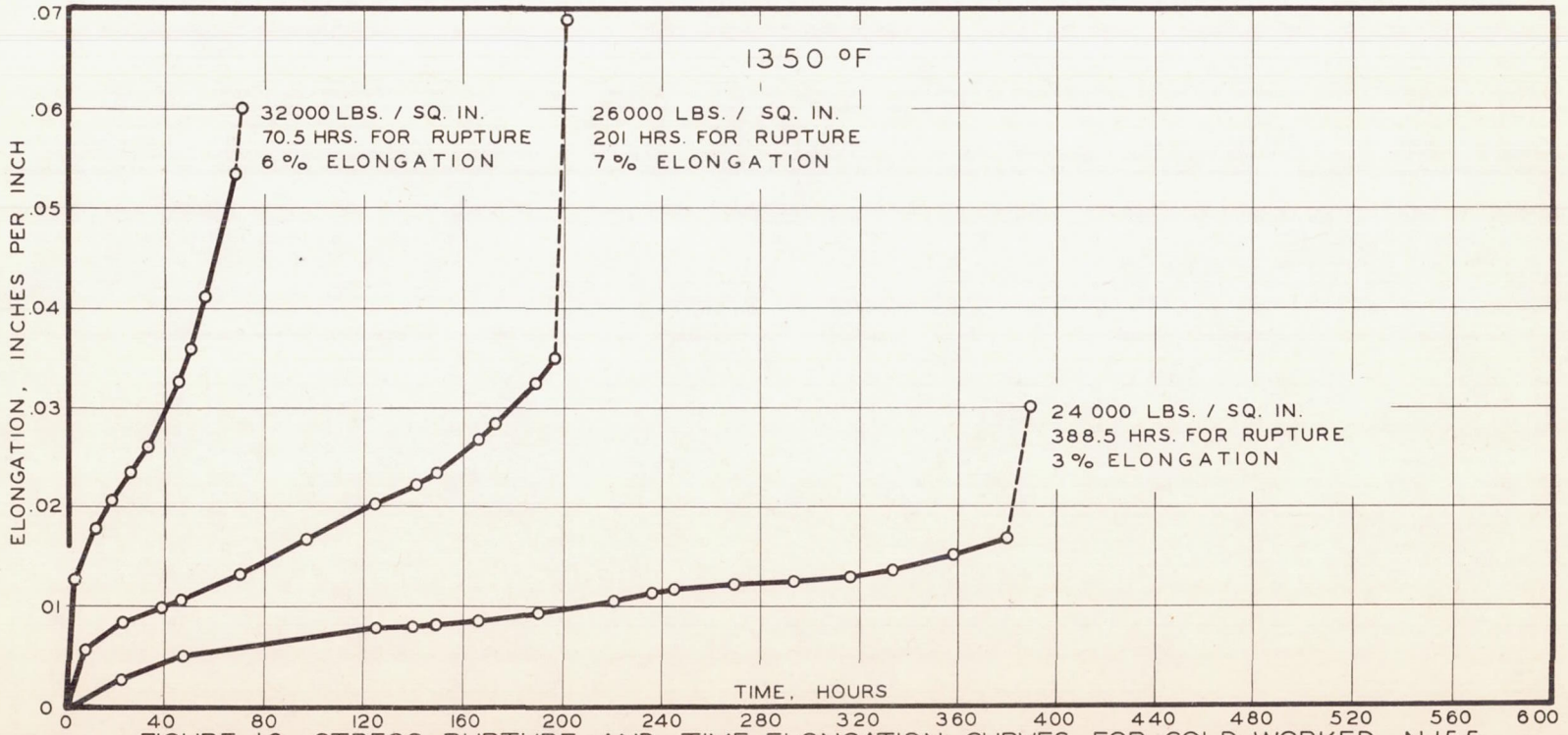


FIGURE 19 - STRESS-RUPTURE AND TIME-ELONGATION CURVES FOR COLD-WORKED N155

ALLOY N156 - Annealed*

MANUFACTURER Universal-Cyclops Steel Corporation and Union Carbide and Carbon Research Laboratories, Inc.

COMPOSITION 0.33% C, 0.57% Si, 1.48% Mn, 15.66% Cr, 33.23% Ni, 23.69% Co, 3.02% Mo, 2.10% W, 1.03% Cb, 0.04% N_2

TREATMENT Melted in an electric arc furnace, 600 pound heat, cast in 45 pound ingot. Hammer forged at 2075/1340°F. to 3/4 inch square bar. Heated 1 hour at 2100°F. and air cooled.

HARDNESS 208 Brinell

TENSILE PROPERTIES

Temperature Deg. F.	Tensile Strength Lb./Sq.In.	Yield Stress Lb./Sq.In. 0.02%	Yield Stress Lb./Sq.In. 0.2%	Proportional Limit Lb./Sq.In.	Elongation % in 2 In.	Reduction of Area %
80	124,000	37,500	57,000	20,000	37.0	37.8
	122,750	37,500	56,500	25,000	35.0	44.1
1200	89,000		41,000	27,500	16.0	19.3
	87,250		43,000	32,500	15.0	16.1

STRESS-RUPTURE DATA

Temperature Deg. F.	Stress Lb./Sq.In.	Time for Rupture Hours	Elongation % in 1 In.	Reduction of Area %
1200	77,000	1.33	12.0	18.2
	70,000	5.43	10.0	12.5
	50,000	90.0	16.0	23.5
	40,000	333.0	9.0	13.2
	30,000	1885.0	7.0	14.8
1350	30,000	38.0	34.0	33.0
	26,000	102.0	30.0	26.6

STRESS-RUPTURE STRENGTHS
(from stress-rupture time plot)

Time for Rupture Hours	Stress Lb./Sq.In. 1200°F.	Stress Lb./Sq.In. 1350°F.
1	79,000	
10	67,000	
100	49,000	26,000
1000	33,000	

*Alloys N156 - Annealed, N156 - Hot Worked and N156 - "Cold" Worked are from the same heat and differ only in processing.



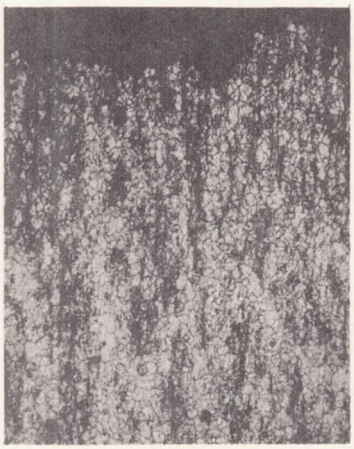
100X



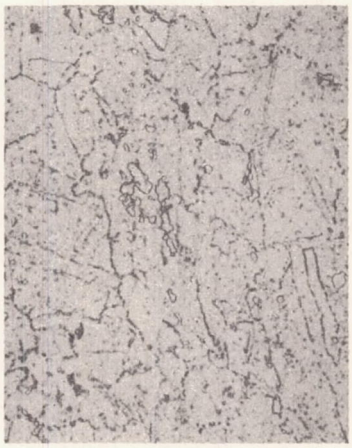
1000X

As Received

Vickers Hardness - 238



Fracture - 100X

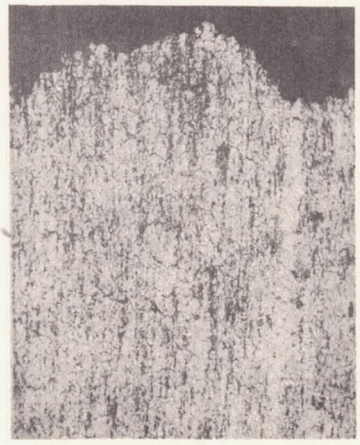


Interior - 1000X

1200°F.

30,000 Lbs. per Sq. In.
1885.0 Hrs. to Rupture

Vickers Hardness - 264



Fracture - 100X



Interior - 1000X

1350°F.

26,000 Lbs. per Sq. In.
102.0 Hrs. to Rupture

Vickers Hardness - 251

MICROSTRUCTURES OF ALLOY N156 - ANNEALED
AS RECEIVED AND AFTER RUPTURE TESTS AT 1200 AND 1350°F.

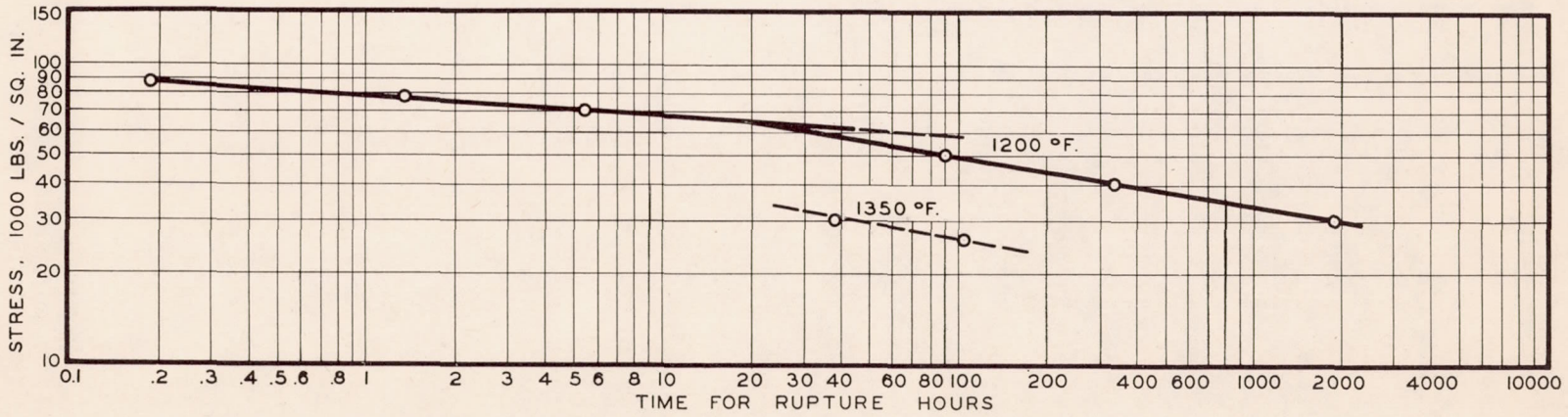


FIGURE 20 - STRESS-RUPTURE CURVES FOR ANNEALED N156

ALLOY N156 - Hot Worked*

MANUFACTURER Universal-Cyclops Steel Corporation and Union Carbide and Carbon Research Laboratories, Inc.

COMPOSITION 0.33% C, 0.57% Si, 1.48% Mn, 15.66% Cr, 33.23% Ni, 23.69% Co, 3.02% Mo, 2.10% W, 1.03% Cb, 0.04% N_2

TREATMENT Melted in an electric arc furnace, 600 pound heat, cast in 45 pound ingot. Hammer forged at 2075/1600°F. to 7/8 inch square bar. Heated 1 hour at 2100°F. and air cooled. Reheated to 1700°F. and reduced in area 26.32% by rolling. Stress relieved by heating through at 1200°F. and air cooled.

HARDNESS 303 Brinell

TENSILE PROPERTIES

Temperature Deg. F.	Tensile Strength Lb./Sq.In.	Yield Stress Lb./Sq.In. 0.02%	Yield Stress Lb./Sq.In. 0.2%	Proportional Limit Lb./Sq.In.	Elongation % in 2 In.	Reduction of Area %
80	146,250	105,500	123,000	82,500	18.5	36.0
	148,000	103,500	124,000	82,500	18.5	36.0
1200	106,625		92,500	42,500	16.0	29.5

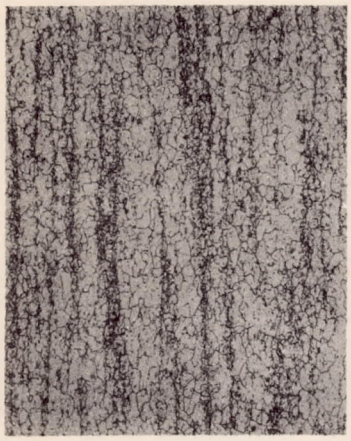
STRESS-RUPTURE DATA

Temperature Deg. F.	Stress Lb./Sq.In.	Time for Rupture Hours	Elongation % in 1 In.	Reduction of Area %
1200	90,000	0.92	12.0	23.8
	84,000	2.43	14.0	29.3
	60,000	66.0	20.0	24.9
	52,000	171.0	11.0	24.5
	45,000	810.0	3.0	8.5
1350	32,000	54.5	5.0	6.2
	26,000	302.0	4.0	3.7
	22,000	866.0	2.0	1.3

STRESS-RUPTURE STRENGTHS
(from stress-rupture time plot)

Time for Rupture Hours	Stress Lb./Sq.In. 1200°F.	Stress Lb./Sq.In. 1350°F.
1	91,000	
10	72,000	
100	56,000	29,000
1000	44,000	22,000

*Alloy N156 - Annealed, N156 - Hot Worked and N156 - "Cold" Worked are from the same heat and differ only in processing.



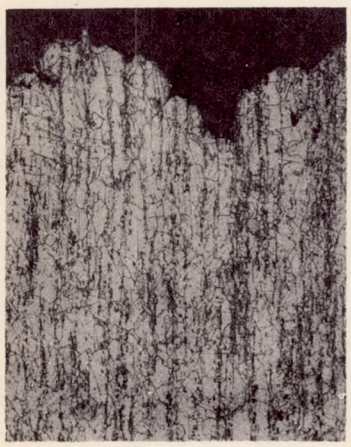
100X



1000X

As Received

Vickers Hardness - 283



Fracture - 100X

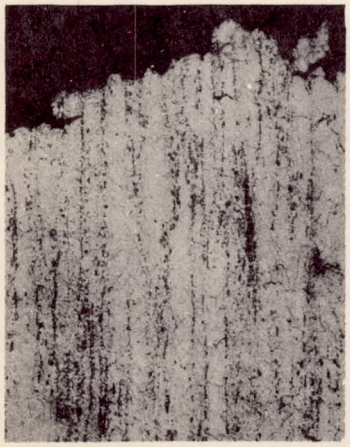


Interior - 1000X

1200°F.

45,000 Lbs. per Sq. In.
810.0 Hrs. to Rupture

Vickers Hardness - 291



Fracture - 100X



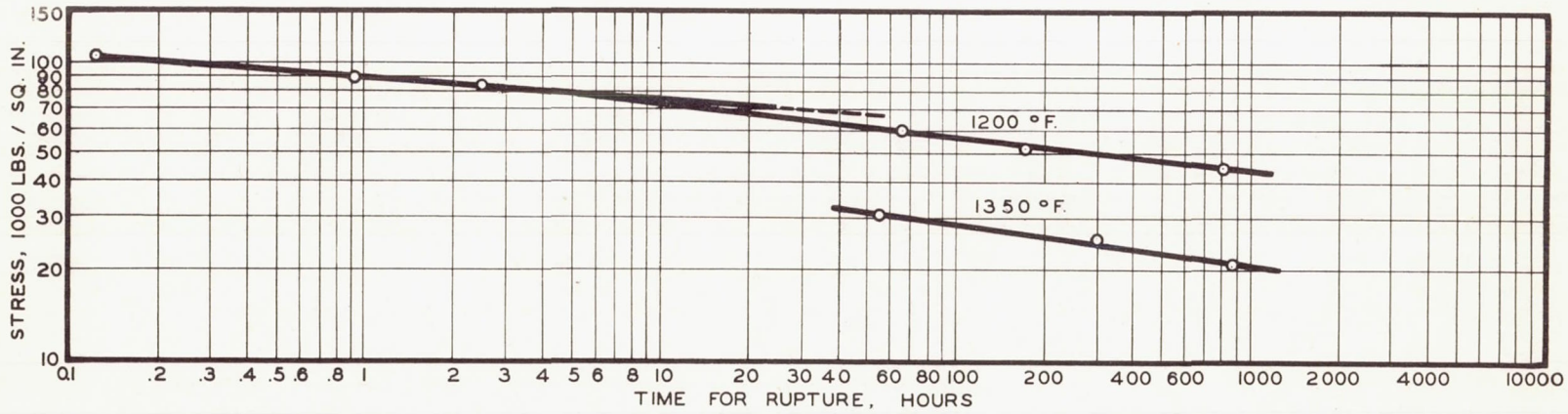
Interior - 1000X

1350°F.

22,000 Lbs. per Sq. In.
866.0 Hrs. to Rupture

Vickers Hardness - 276

MICROSTRUCTURES OF ALLOY N156 - HOT WORKED
AS RECEIVED AND AFTER RUPTURE TESTS AT 1200 AND 1350°F.



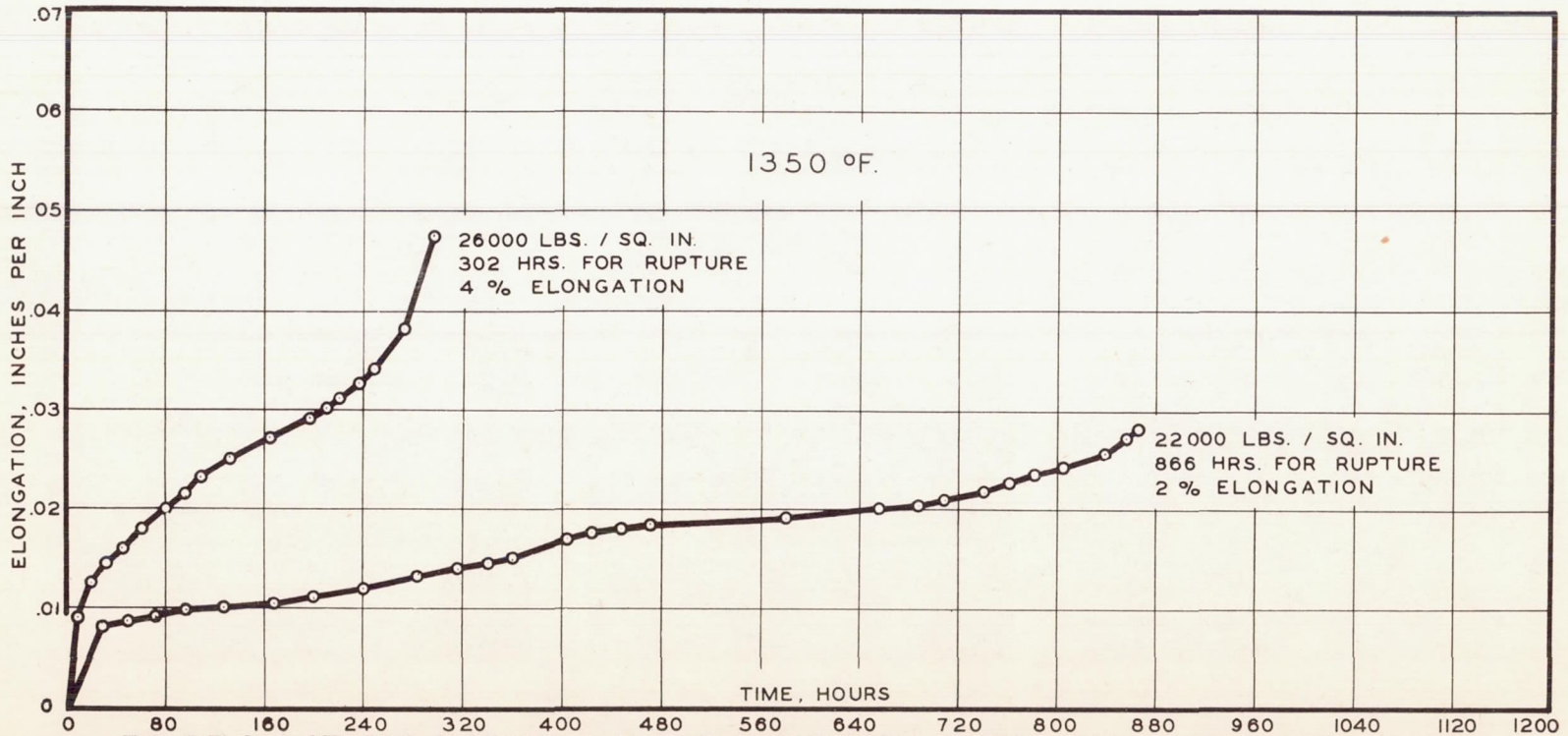


FIGURE 21 - STRESS-RUPTURE AND TIME-ELONGATION CURVES FOR HOT-WORKED N 156

ALLOY N156 - "Cold" Worked

MANUFACTURER Universal-Cyclops Steel Corporation and Union Carbide and Carbon Research Laboratories, Inc.

COMPOSITION 0.33% C, 0.57% Si, 1.48% Mn, 15.66% Cr, 33.23% Ni, 23.69% Co, 3.02% Mo, 2.10% W, 1.03% Cb, 0.04% N_2

TREATMENT Melted in an electric arc furnace, 600 pound heat, cast in 45 pound ingot. Hammer forged at 2075/1600°F. to 7/8 inch square bar. Heated 1 hour at 2100°F. and air cooled. Reheated to 1200°F. and reduced in area 24.24% by rolling. Stress relieved by heating through at 1200°F. and air cooled.

HARDNESS 338 Brinell

TENSILE PROPERTIES

Temperature Deg. F.	Tensile Strength Lb./Sq.In.	Yield Stress Lb./Sq.In. 0.02%	Yield Stress Lb./Sq.In. 0.2%	Proportional Limit Lb./Sq.In.	Elongation % in 2 In.	Reduction of Area %
80	168,750	130,500	153,800	107,500	14.5	33.7
	168,000	123,000	149,000	102,500	13.0	29.5
1200	119,750		110,000	67,500	10.5	22.7

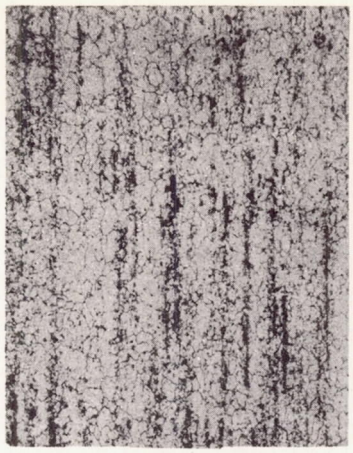
STRESS-RUPTURE DATA

Temperature Deg. F.	Stress Lb./Sq.In.	Time for Rupture Hours	Elongation % in 1 In.	Reduction of Area %
1200	98,000	1.10	10.0	23.3
	88,000	3.38	10.0	21.8
	60,000	78.0	5.0	8.6
	53,000	236.0	4.0	6.2
	45,000	770.0	2.0	7.3
1350	32,000	74.0	4.0	3.7
	26,000	272.5	2.0	2.5
	24,000	400.5	3.0	2.5

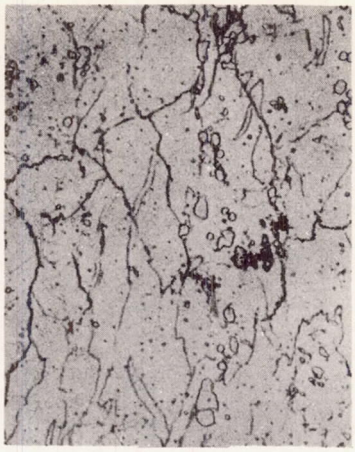
STRESS-RUPTURE STRENGTHS
(from stress-rupture time plot)

Time for Rupture Hours	Stress Lb./Sq.In. 1200°F.	Stress Lb./Sq.In. 1350°F.
1	99,000	
10	78,000	
100	59,000	30,000
1000	44,000	20,500

*Alloys N156 - Annealed, N156 - Hot Worked and N156 - "Cold" Worked are from the same heat and differ only in processing.



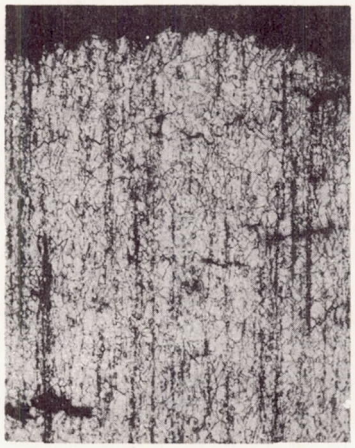
100X



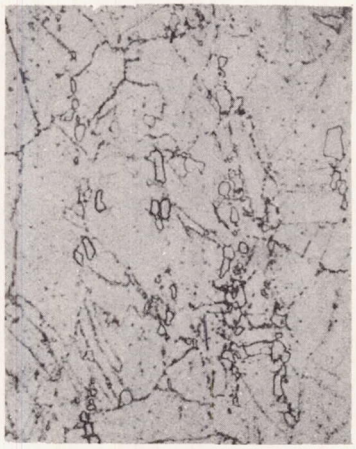
1000X

As Received

Vickers Hardness - 351



Fracture - 100X

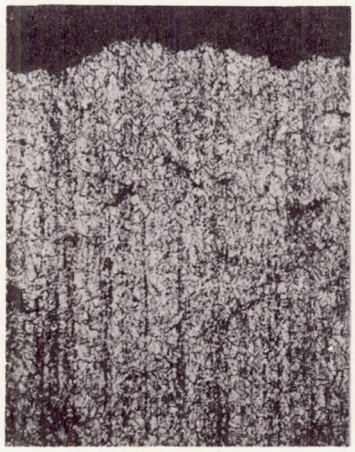


Interior - 1000X

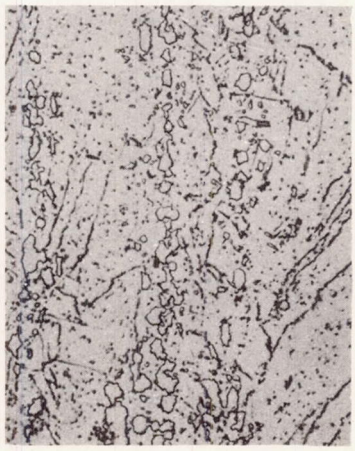
1200°F.

45,000 Lbs. per Sq. In.
770.0 Hrs. to Rupture

Vickers Hardness - 320



Fracture - 100X



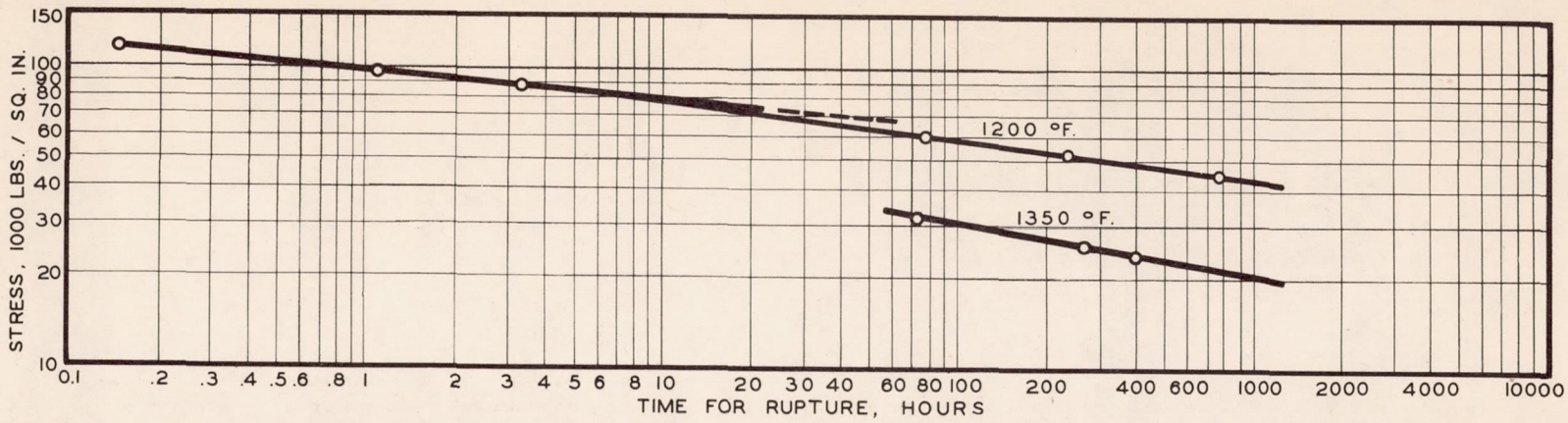
Interior - 1000X

1350°F.

24,000 Lbs. per Sq. In.
400.5 Hrs. to Rupture

Vickers Hardness - 298

MICROSTRUCTURES OF ALLOY N156 - COLD WORKED
AS RECEIVED AND AFTER RUPTURE TESTS AT 1200 AND 1350°F.



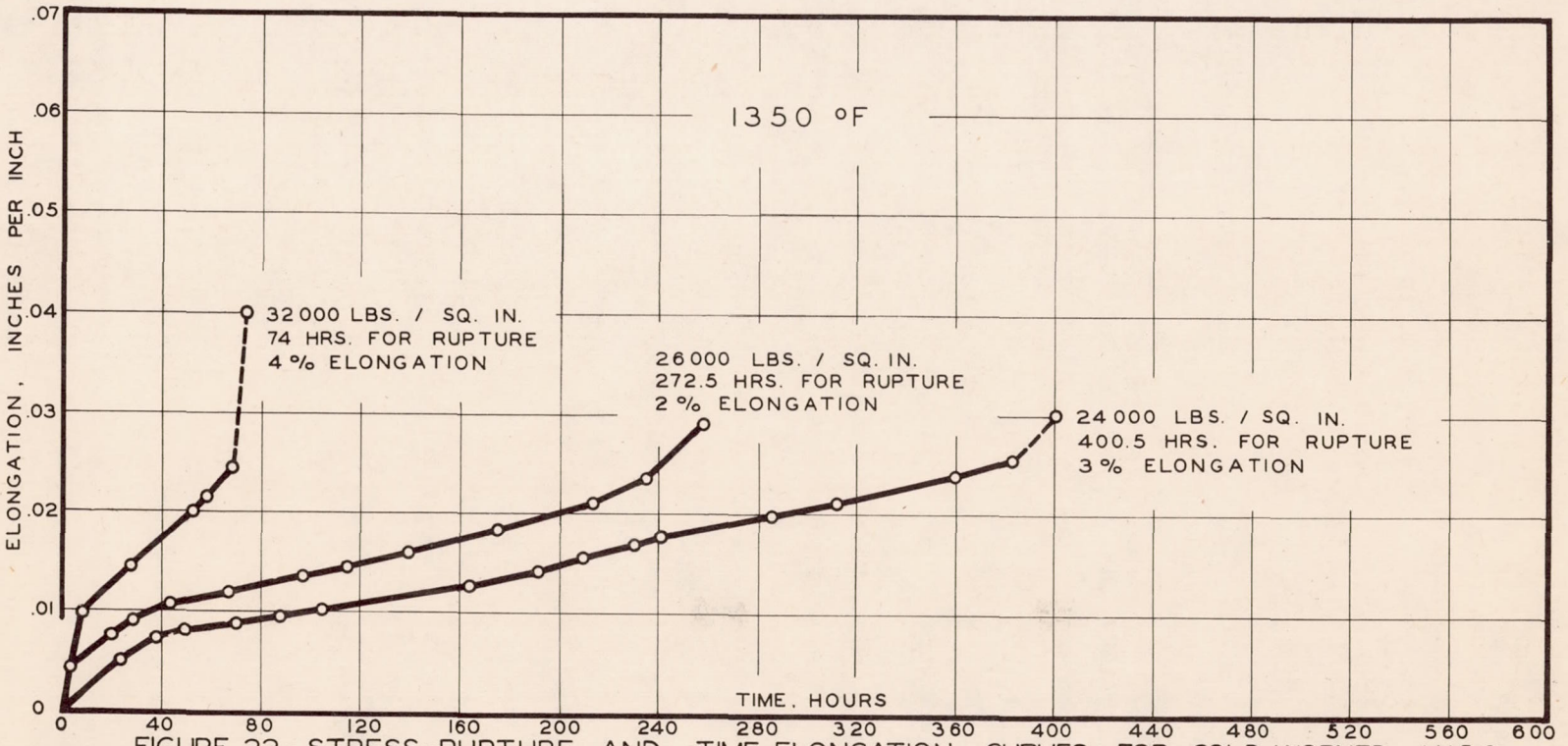


FIGURE 22 - STRESS-RUPTURE AND TIME-ELONGATION CURVES FOR COLD-WORKED N156

ALLOY Low Carbon N153 (H992 and J65)

MANUFACTURER Union Carbide and Carbon Research Laboratories, Inc.

COMPOSITION 0.10% C, 0.50% Si, 1.5% Mn, 15% Cr, 15% Ni, 13% Co, 3% Mo, 2% W, 1% Cb, 0.10% N.

TREATMENT 2 inch square induction furnace ingot Hammer forged at 2100/1350°F. to 1 inch square bar, reheated three times.

HARDNESS 254 Brinell

TENSILE PROPERTIES

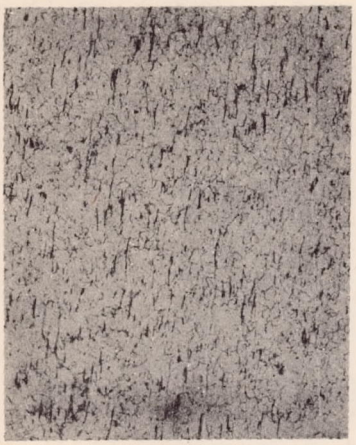
Heat	Temperature Deg. F.	Tensile Strength Lb./Sq.In.	Yield Stress Lb./Sq.In. 0.02%	Yield Stress Lb./Sq.In. 0.2%	Proportional Limit Lb./Sq.In.	Elongation % in 2 In.	Reduction of Area %
H992	80	119,700	76,300	96,500	52,500	27.0	62.1
		118,600	72,000	89,400	50,000	32.5	61.6
H992	1200	84,400		69,700	37,500	29.0	47.1
		80,500		68,300	35,000	27.0	48.7
J65	80	121,500	72,700	93,200	45,000	31.0	58.3
		115,000	66,800	82,800	45,000	32.5	57.2
J65	1200	85,250		65,200	35,000	25.0	40.7
J65	1350	69,750		49,600	22,500	40.0	50.0
		62,750		50,000	22,500	33.0	48.1

STRESS-RUPTURE DATA

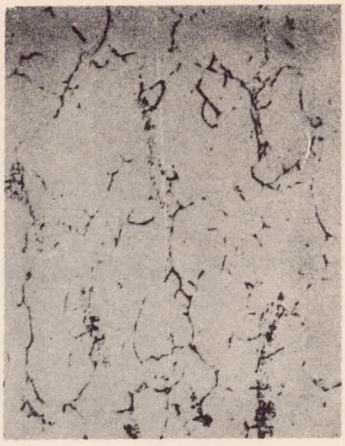
Heat	Temperature Deg. F.	Stress Lb./Sq.In.	Time for Rupture Hours	Elongation % in 1 In.	Reduction of Area %
H992	1200	78,000	1.13	13.0	38.0
		73,000	3.20	15.0	32.3
		60,000	40.0	15.0	33.6
		55,000	113.0	15.0	33.0
		50,000	507.0	12.0	34.0
H992	1350	35,000	54.0	17.0	37.2
		30,000	195.5	12.0	23.4
J65	1350	62,000	0.23	21.0	45.5
		52,000	0.8	12.0	23.4
		40,000	51.0	7.0	14.4
		30,000	231.0	6.0	12.1

STRESS-RUPTURE STRENGTHS
(from stress-rupture time plot)

Time for Rupture Hours	Stress Lb./Sq.In. 1200°F.	Stress Lb./Sq.In. 1350°F.
1	79,000	53,000
10	66,000	42,000
100	55,500	32,500
1000	47,000	



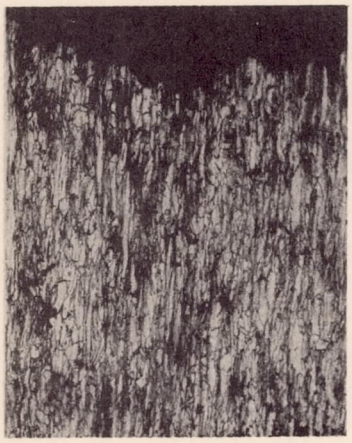
100X



1000X

As Received

Vickers Hardness - 260



Fracture - 100X

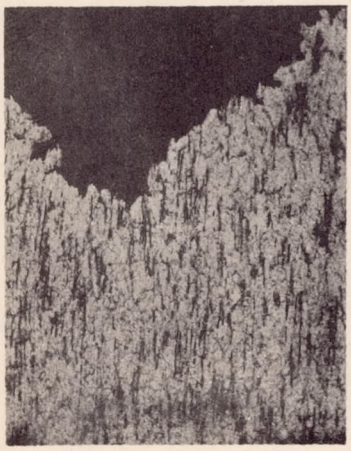


Interior - 1000X

1200°F.

50,000 Lbs. per Sq. In.
507.0 Hrs. to Rupture

Vickers Hardness - 288



Fracture - 100X



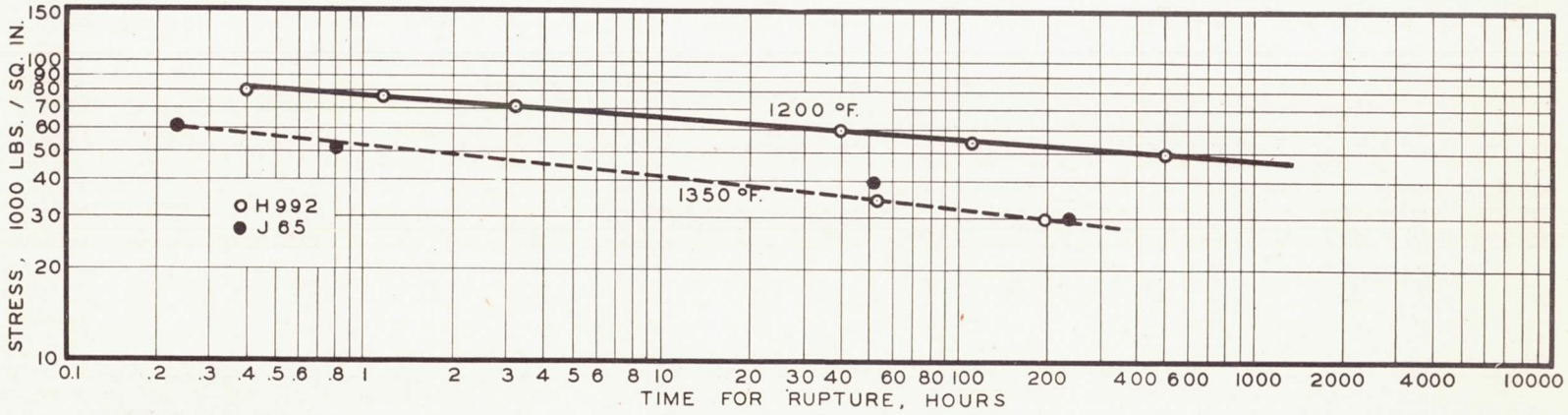
Interior - 1000X

1350°F.

30,000 Lbs. per Sq. In.
195.5 Hrs. to Rupture

Vickers Hardness - 272

MICROSTRUCTURES OF LOW CARBON ALLOY N153 (H992)
AS RECEIVED AND AFTER RUPTURE TESTS AT 1200 AND 1350°F.



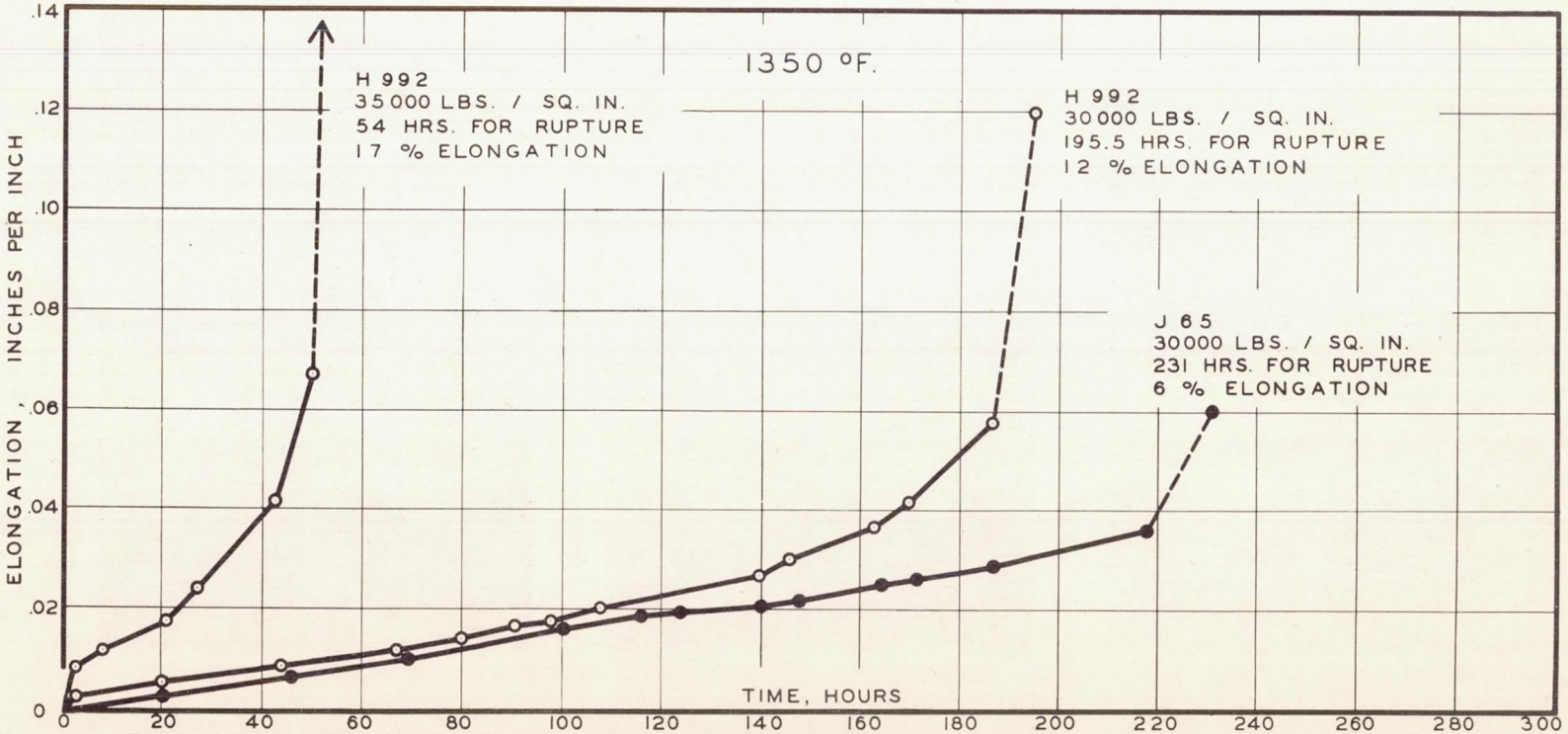


FIGURE 23 - STRESS-RUPTURE AND TIME-ELONGATION CURVES FOR LOW-CARBON N153

W-93

ALLOY	Low Carbon N154 (H993 and J66)
MANUFACTURER	Union Carbide and Carbon Research Laboratories, Inc.
COMPOSITION	0.10% C, 0.50% Si, 1.5% Mn, 15% Cr, 24% Ni, 20% Co, 3% Mo, 2% W, 1% Cb, 0.10% N.
TREATMENT	2 inch square induction furnace ingots. Hammer forged at 2100/1350°F. to 1 inch square bar, reheating three times.
HARDNESS	251 Brinell

TENSILE PROPERTIES

Heat	Temperature Deg. F.	Tensile Strength Lb./Sq.In.	Yield Stress Lb./Sq.In. 0.02%	Yield Stress Lb./Sq.In. 0.2%	Proportional Limit Lb./Sq.In.	Elongation % in 2 In.	Reduction of Area %
H993	80	121,500	73,100	84,700	55,000	27.0	62.2
		125,500	82,500	95,000	65,000	30.5	58.8
H993	1200	84,650		60,700	30,000	22.5	31.8
		89,300		72,500	25,000	24.0	33.7
J66	80	132,000	77,300	98,000	50,000	30.0	50.2
		133,000	82,000	102,000	60,000	27.0	56.9
J66	1200	96,625		73,500	42,500	20.0	39.1
J66	1350	69,625		56,000	27,500	32.5	47.8
		75,000		57,200	27,500	14.5	41.3

STRESS-RUPTURE DATA

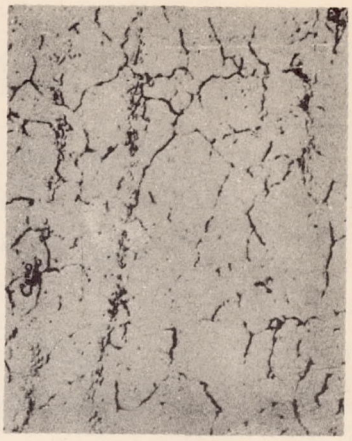
Heat	Temperature Deg. F.	Stress Lb./Sq.In.	Time for Rupture Hours	Elongation % in 1 In.	Reduction of Area %
H993	1200	82,000	1.95	9.0	17.3
		78,000	3.08	7.0	10.2
		60,000	44.5	6.0	13.8
		50,000	282.5	7.0	22.8
		46,000	459.5	9.0	13.2
	1350	35,000	101.0	17.0	34.0
		30,000	146.5	6.0	30.3
J66	1350	65,000	0.50	15.0	13.3
		40,000	48.0	26.0	43.5
		30,000	320.0	6.0	8.6

STRESS-RUPTURE STRENGTHS
(from stress-rupture time plot)

Time for Rupture Hours	Stress Lb./Sq.In. 1200°F.	Stress Lb./Sq.In. 1350°F.
1	87,000	61,000
10	69,000	46,000
100	54,500	35,000
1000	44,000	



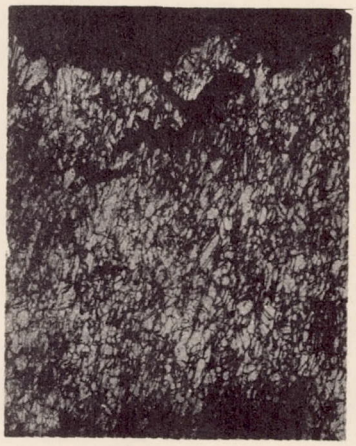
100X



1000X

As Received

Vickers Hardness - 251



Fracture - 100X

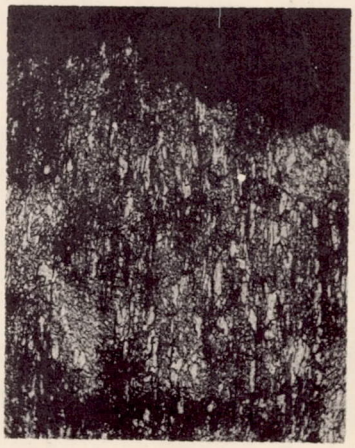


Interior - 1000X

1200°F.

46,000 Lbs. per Sq. In.
459.5 Hrs. to Rupture

Vickers Hardness - 278



Fracture - 100X



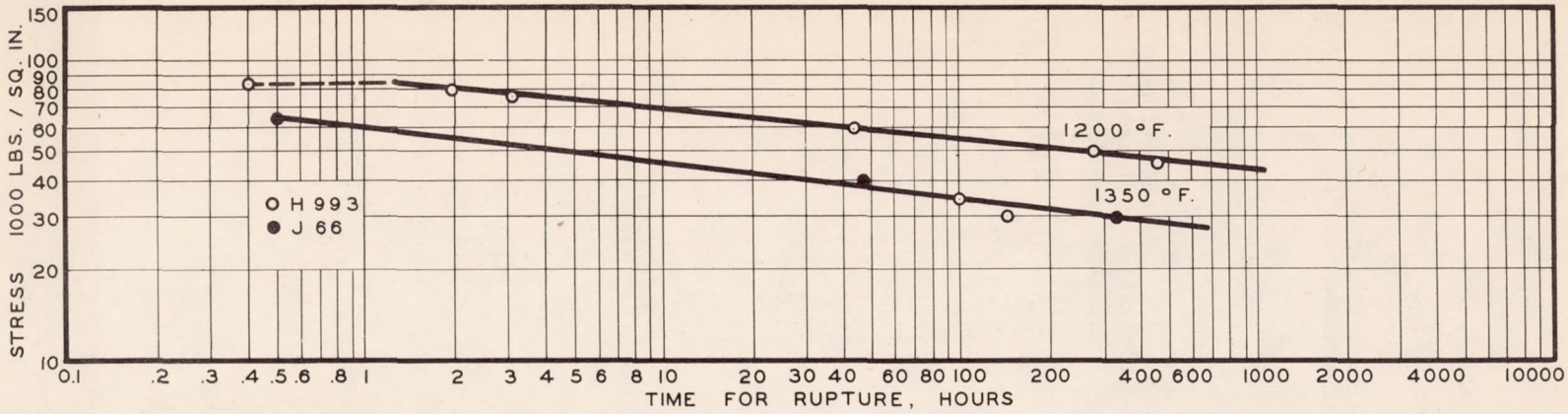
Interior - 1000X

1350°F.

30,000 Lbs. per Sq. In.
146.5 Hrs. to Rupture

Vickers Hardness - 280

MICROSTRUCTURES OF LOW CARBON ALLOY N154 (H993)
AS RECEIVED AND AFTER RUPTURE TESTS AT 1200 AND 1350°F.



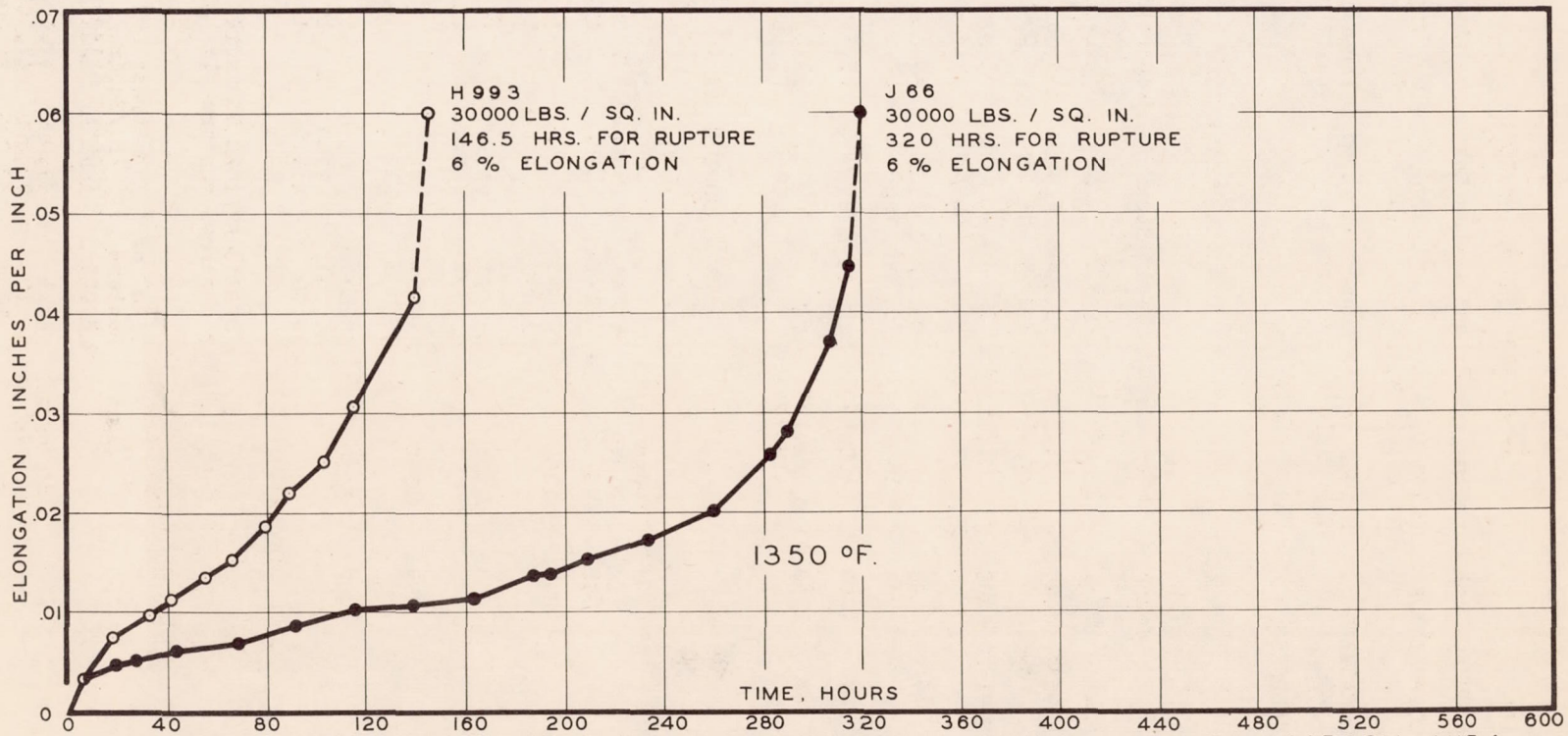


FIGURE 24- STRESS-RUPTURE AND TIME-ELONGATION CURVES FOR LOW CARBON N154

ALLOY Low Carbon N155 (H994 and J67)

MANUFACTURER Union Carbide and Carbon Research Laboratories, Inc.

COMPOSITION 0.10% C, 0.50% Si, 1.5% Mn, 20% Cr, 20% Ni, 20% Co, 3% Mo, 2% W, 1% Cb, 0.10% N.

TREATMENT 2 inch square induction furnace ingots. Hammer forged at 2100/1350°F. to 1 inch square bar, reheating three times.

HARDNESS 268 Brinell

TENSILE PROPERTIES

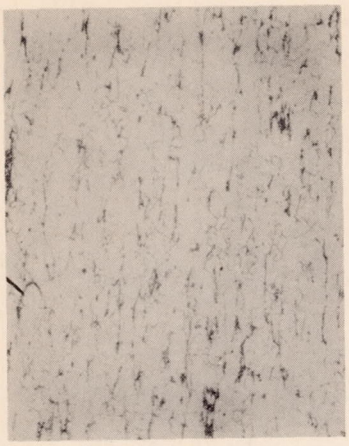
Heat	Temperature Deg. F.	Tensile Strength Lb./Sq.In.	Yield Stress Lb./Sq.In. 0.02%	Yield Stress Lb./Sq.In. 0.2%	Proportional Limit Lb./Sq.In.	Elongation % in 2 In.	Reduction of Area %
H994	80	135,250	83,800	101,900	65,000	32.5	52.6
		133,500	79,800	94,300	60,000	33.0	56.0
H994	1200	91,700		69,600	25,000	29.0	41.3
		89,500		60,800	32,500	29.0	31.3
J67	80	137,750	83,200	104,000	50,000	28.5	49.1
		136,000	75,700	95,600	42,500	34.0	50.2
J67	1200	100,500		79,700	37,500	22.5	34.1
J67	1350	84,125		70,300	30,000	23.5	37.2
		77,750		61,000	22,500	25.0	36.4

STRESS-RUPTURE DATA

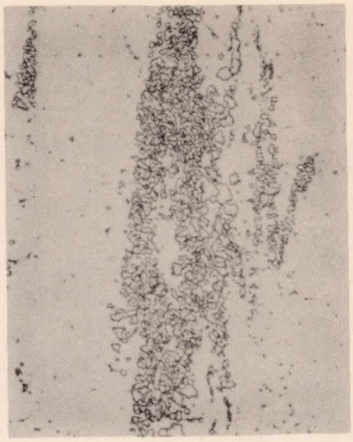
Heat	Temperature Deg. F.	Stress Lb./Sq.In.	Time for Rupture Hours	Elongation % in 1 In.	Reduction of Area %
H994	1200	86,000	1.62	16.0	26.1
		82,000	2.55	15.5	25.5
		60,000	70.0	14.0	32.3
		55,000	219.5	12.0	23.4
		50,000	548.0	14.0	48.3
H994	1350	35,000	88.0	11.0	38.0
		30,000	437.0	6.0	13.2
J67	1350	68,000	0.50	12.0	21.2
		40,000	75.0	17.0	37.0
		30,000	439.0	12.0	27.7

STRESS-RUPTURE STRENGTHS
(from stress-rupture time plot)

Time for Rupture Hours	Stress Lb./Sq.In. 1200°F.	Stress Lb./Sq.In. 1350°F.
1	89,000	62,000
10	72,000	47,000
100	58,000	36,000
1000	48,000	27,500



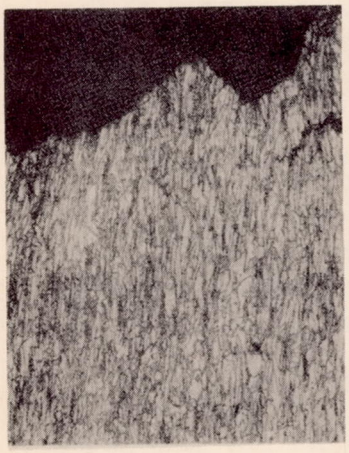
100X



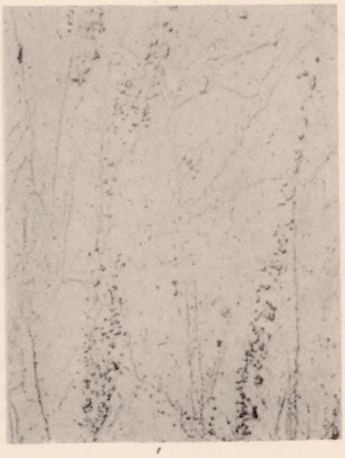
1000X

As Received

Vickers Hardness - 304



Fracture - 100X

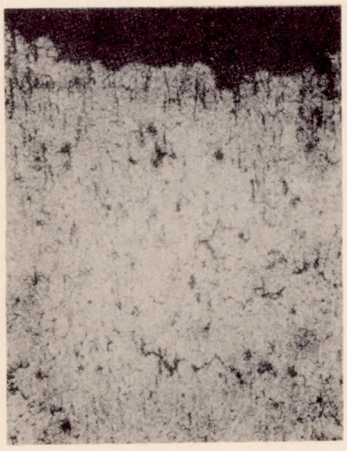


Interior - 1000X

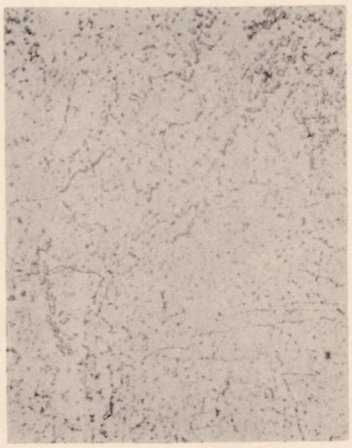
1200°F.

50,000 Lbs. per Sq. In.
548.0 Hrs. to Rupture

Vickers Hardness - 313



Fracture - 100X



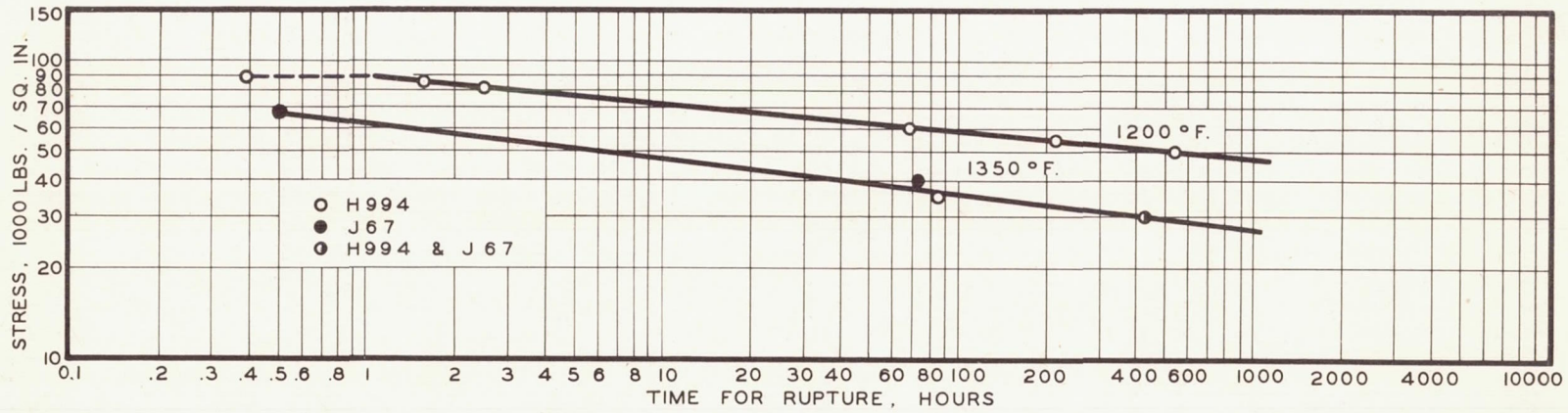
Interior - 1000X

1350°F.

30,000 Lbs. per Sq. In.
437.0 Hrs. to Rupture

Vickers Hardness - 298

MICROSTRUCTURES OF LOW CARBON ALLOY N155 (H994)
AS RECEIVED AND AFTER RUPTURE TESTS AT 1200 AND 1350°F.



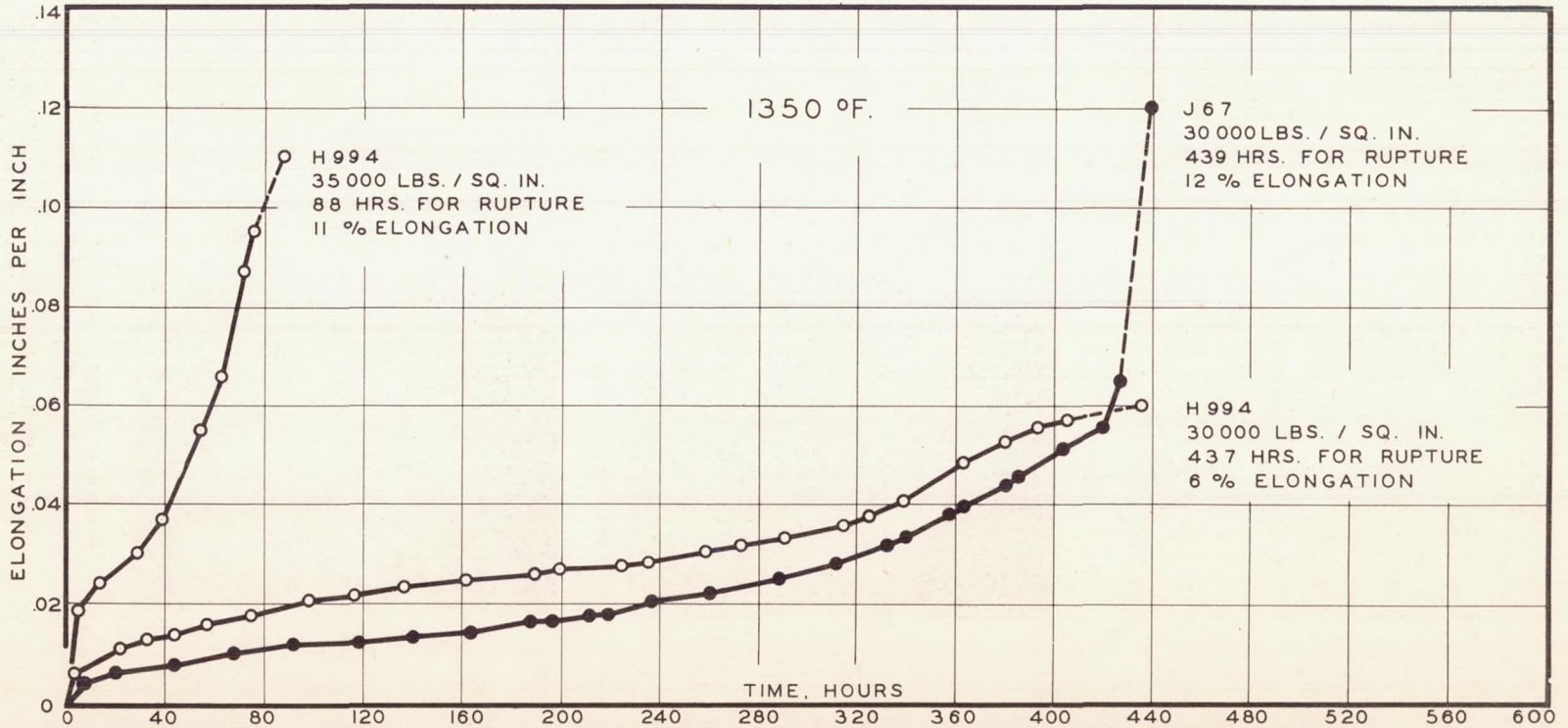


FIGURE 25- STRESS-RUPTURE AND TIME-ELONGATION CURVES FOR LOW CARBON N155

ALLOY Age Hardenable Inconel

MANUFACTURER International Nickel Company, Inc.

COMPOSITION 0.03% C, 0.52% Si, 0.53% Mn, 0.10% Cu, 74.82% Ni, 14.40% Cr, 0.63% Al, 2.77% Ti, 6.17% Fe, .007% S.

TREATMENT Hot rolled 7/8 inch round bar. Heated 2 hours at 1950°F. and water quenched. Aged 16 hours at 1300°F.

HARDNESS 308 Brinell

TENSILE PROPERTIES

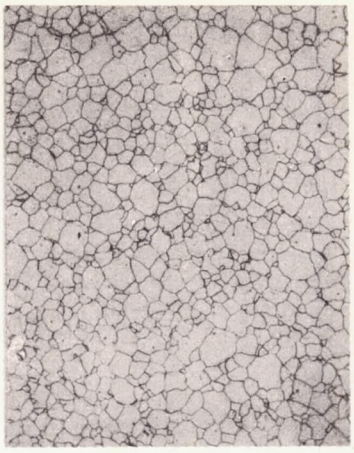
Temperature Deg. F.	Tensile Strength Lb./Sq.In.	Yield Stress Lb./Sq.In. 0.02%	Yield Stress Lb./Sq.In. 0.2%	Proportional Limit Lb./Sq.In.	Elongation % in 2 In.	Reduction of Area %
80	178,500	107,500	119,000	70,000	28.5	41.3
	177,500	101,000	118,300	70,000	27.5	38.9
1200	123,500		108,800	50,000	6.0	11.6
	130,500		107,500	47,500	7.5	10.3

STRESS-RUPTURE DATA

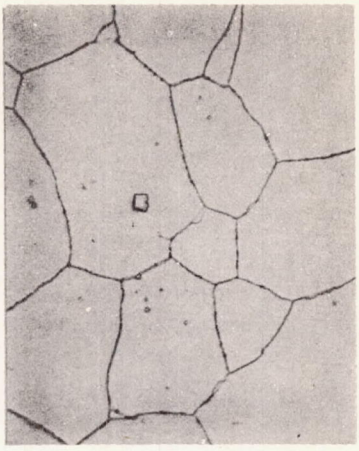
Temperature Deg. F.	Stress Lb./Sq.In.	Time for Rupture Hours	Elongation % in 1 In.	Reduction of Area %
1200	110,000	0.42	5.0	12.1
	90,000	4.85	4.0	10.0
	60,000	88.0	3.0	13.2
	50,000	288.0	1.0	1.2
	45,000	377.0	0	1.2
	44,000	490.5	2.0	0
1350	40,000	83.5	1.0	1.0
	36,000	52.0	1.0	3.7
	32,000	107.5	2.0	3.7
	25,000	262.5	1.0	1.0
	21,000	388.0	3.0	8.5

STRESS-RUPTURE STRENGTHS
(from stress-rupture time plot)

Time for Rupture Hours	Stress Lb./Sq.In. 1200°F.	Stress Lb./Sq.In. 1350°F.
1	103,000	
10	84,000	
100	59,000	32,000
1000	38,000	16,500



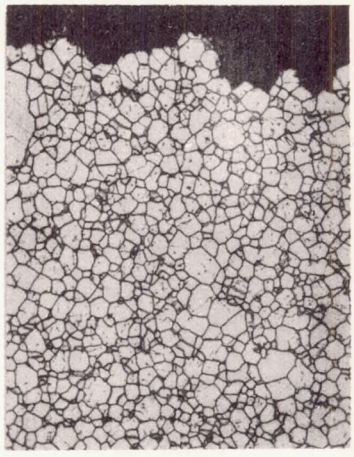
100X



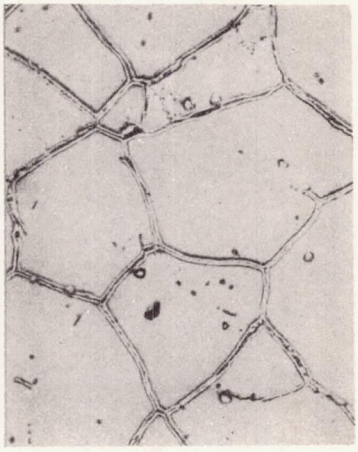
1000X

As Received

Vickers Hardness - 330



Fracture - 100X



Interior - 1000X

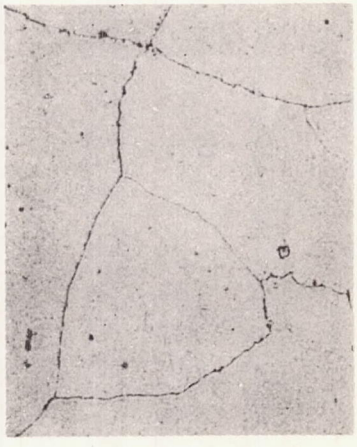
1200°F.

44,000 Lbs. per Sq. In.
490.5 Hrs. to Rupture

Vickers Hardness - 358



Fracture - 100X



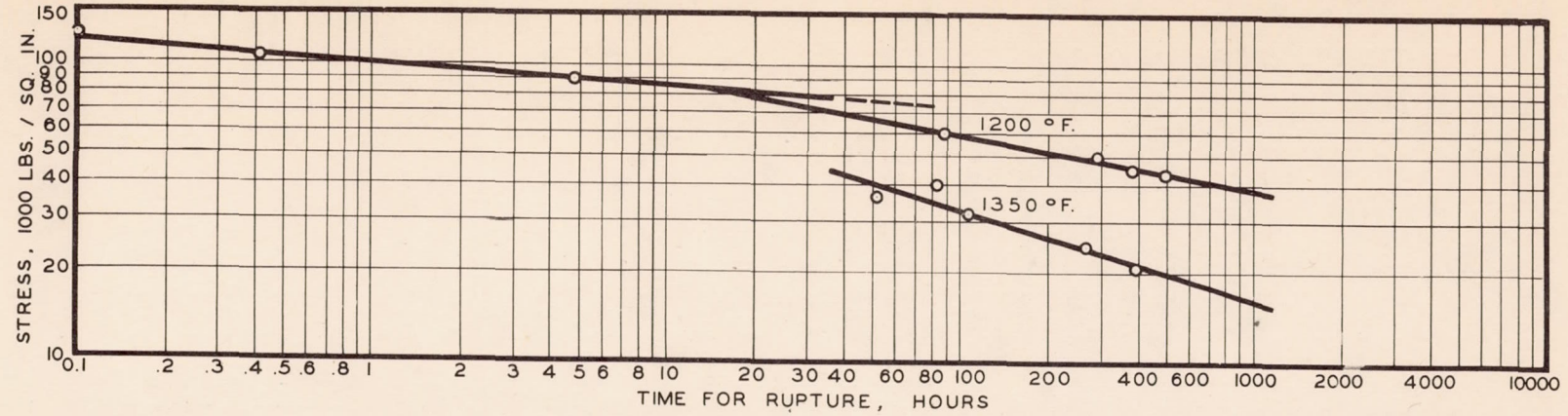
Interior - 1000X

1350°F.

21,000 Lbs. per Sq. In.
388.0 Hrs. to Rupture

Vickers Hardness - 261

MICROSTRUCTURES OF AGE-HARDENABLE INCONEL
AS RECEIVED AND AFTER RUPTURE TESTS AT 1200 AND 1350°F.



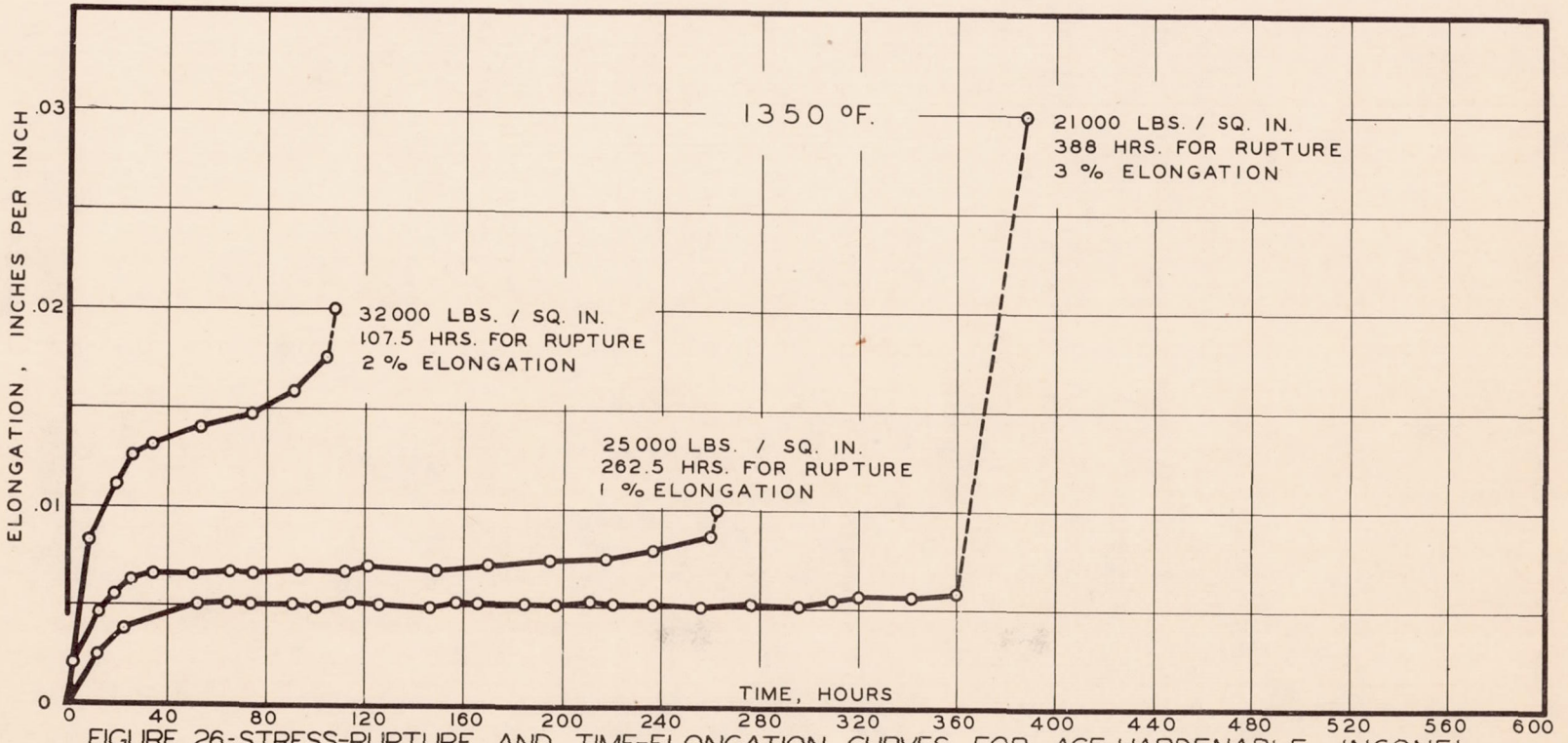


FIGURE 26-STRESS-RUPTURE AND TIME-ELONGATION CURVES FOR AGE-HARDENABLE INCONEL

ALLOY Vitallium (Aged 50 Hours at 1350°F.)

MANUFACTURER Haynes-Stellite Company

COMPOSITION 0.24% C, 28.70% Cr, 5.57% Mo, Balance Co.

TREATMENT Cast by the Dental Investment Process as a 1/4-inch diameter tensile test specimen with a one-inch gauge length. The test specimens were cast complete with threads so that no machining was necessary.

The test bars were aged 50 hours at 1350°F. prior to testing.

The specimens were submitted by National Research Council Project 8 as their alloy designation NR-10D.

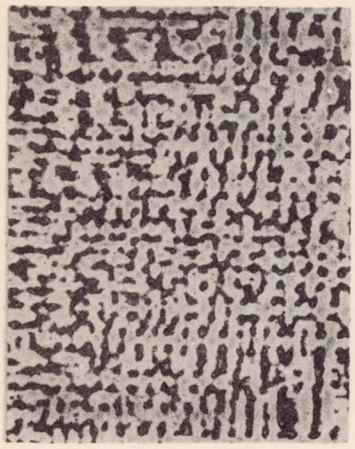
HARDNESS 392 Vickers Brinell

STRESS-RUPTURE DATA AT 1350°F.

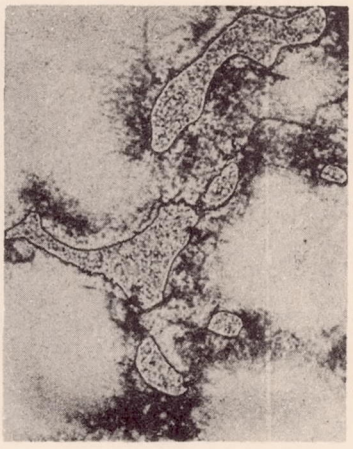
Stress Lb./Sq.In.	Time for Rupture Hours	Elongation % in 1 In.	Reduction of Area %
35,000	40.5	14.0	35.8
30,000	216.0	10.0	26.0
27,000	375.5	3.5	6.4

STRESS-RUPTURE STRENGTHS AT 1350°F.
(from stress-rupture time plot)

Time for Rupture Hours	Stress Lb./Sq.In.
100	32,000
1000	25,000



100X

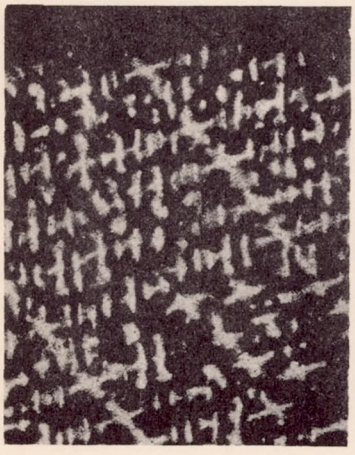


1000X

As Heat Treated

50 Hrs. at 1350°F.

Vickers Hardness - 392



Fracture - 100X



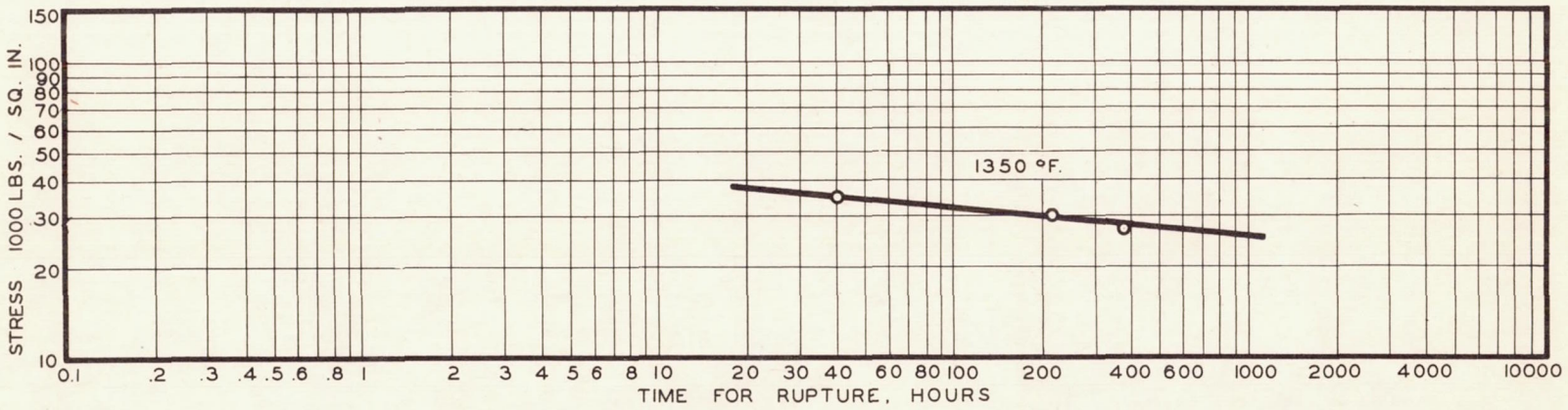
Interior - 1000X

1350°F.

27,000 Lbs. per Sq. In.
375.5 Hrs. to Rupture

Vickers Hardness - 479

MICROSTRUCTURES OF VITALLIUM (NR10) AS HEAT TREATED
AND AFTER RUPTURE TESTS AT 1350°F.



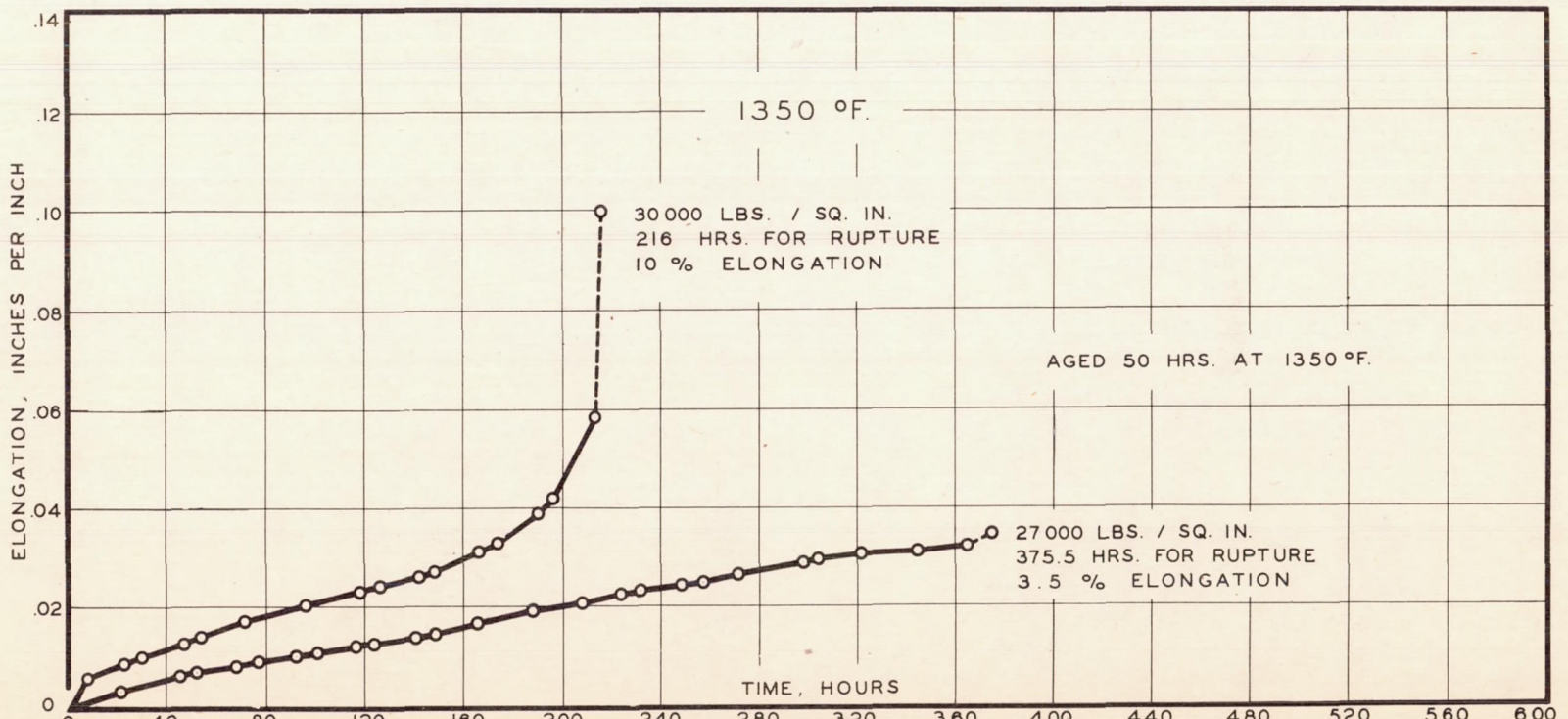


FIGURE 27- STRESS-RUPTURE AND TIME-ELONGATION CURVES FOR CAST VITALLIUM (NR 10)

ALLOY Vitallium (Aged 50 Hours at 1500°F.)

MANUFACTURER Haynes-Stellite Company

COMPOSITION Reported as almost identical to the following analysis: 0.24% C, 28.70% Cr, 5.57% Mo, Balance Co.

TREATMENT Cast by the Dental Investment Process as 1/4-inch diameter tensile test specimens with a one-inch gauge length. The specimens were cast complete with threads so that no machining was necessary.

The test bars were aged 50 hours at 1500°F. prior to testing.

The specimens were submitted by National Research Council Project 8 as their alloy designation NR-10A.

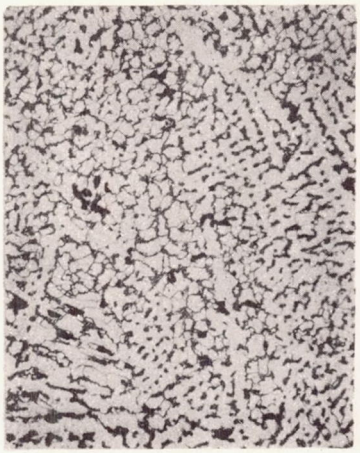
HARDNESS 371 Vickers Brinell

STRESS-RUPTURE DATA AT 1350°F.

Stress Lb./Sq.In.	Time for Rupture Hours	Elongation % in 1 In.	Reduction of Area %
40,000	45.5	28.0	33.2
35,000	177.0	23.0	26.8
30,000	382.5	30.0	44.8

STRESS-RUPTURE STRENGTHS AT 1350°F.
(from stress-rupture time plot)

Time for Rupture Hours	Stress Lb./Sq.In.
100	36,500
1000	28,000



100X

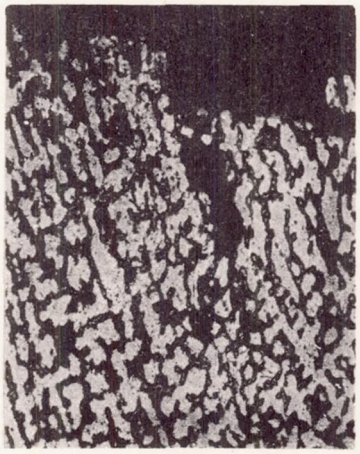


1000X

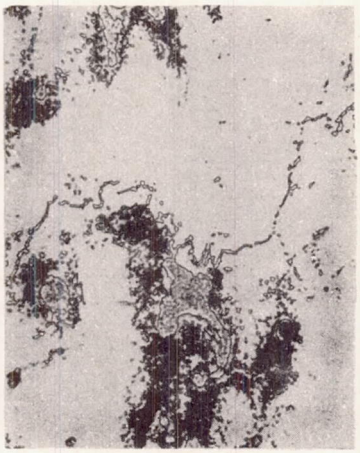
As Heat Treated

50 Hrs. at 1500°F.

Vickers Hardness - 371



Fracture - 100X



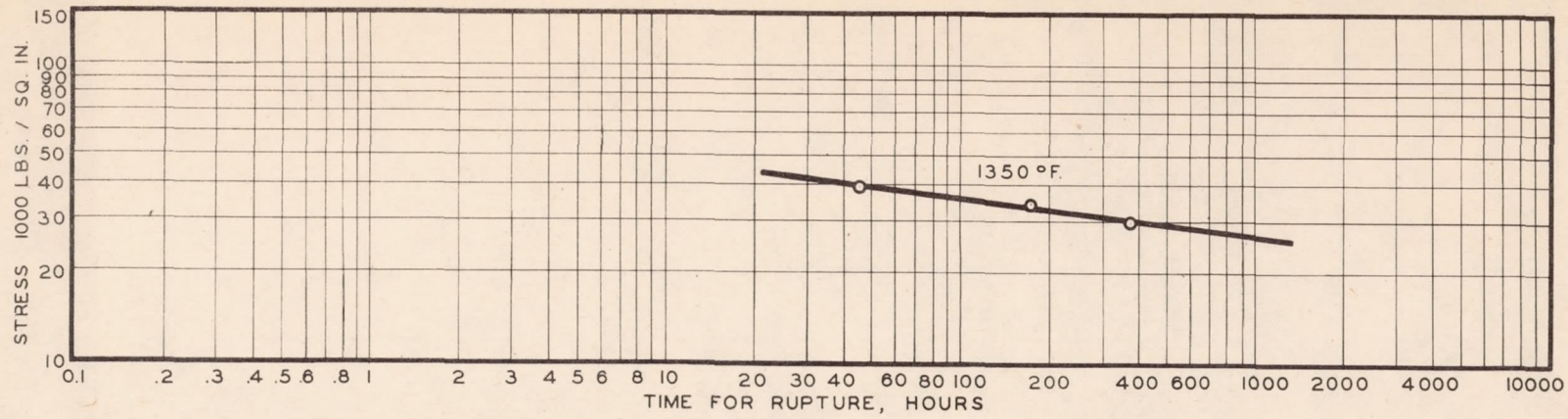
Interior - 1000X

1350°F.

30,000 Lbs. per Sq. In.
382.5 Hrs. to Rupture

Vickers Hardness - 450

MICROSTRUCTURES OF VITALLIUM (NR10) AS HEAT TREATED AND AFTER RUPTURE TESTS AT 1350°F.



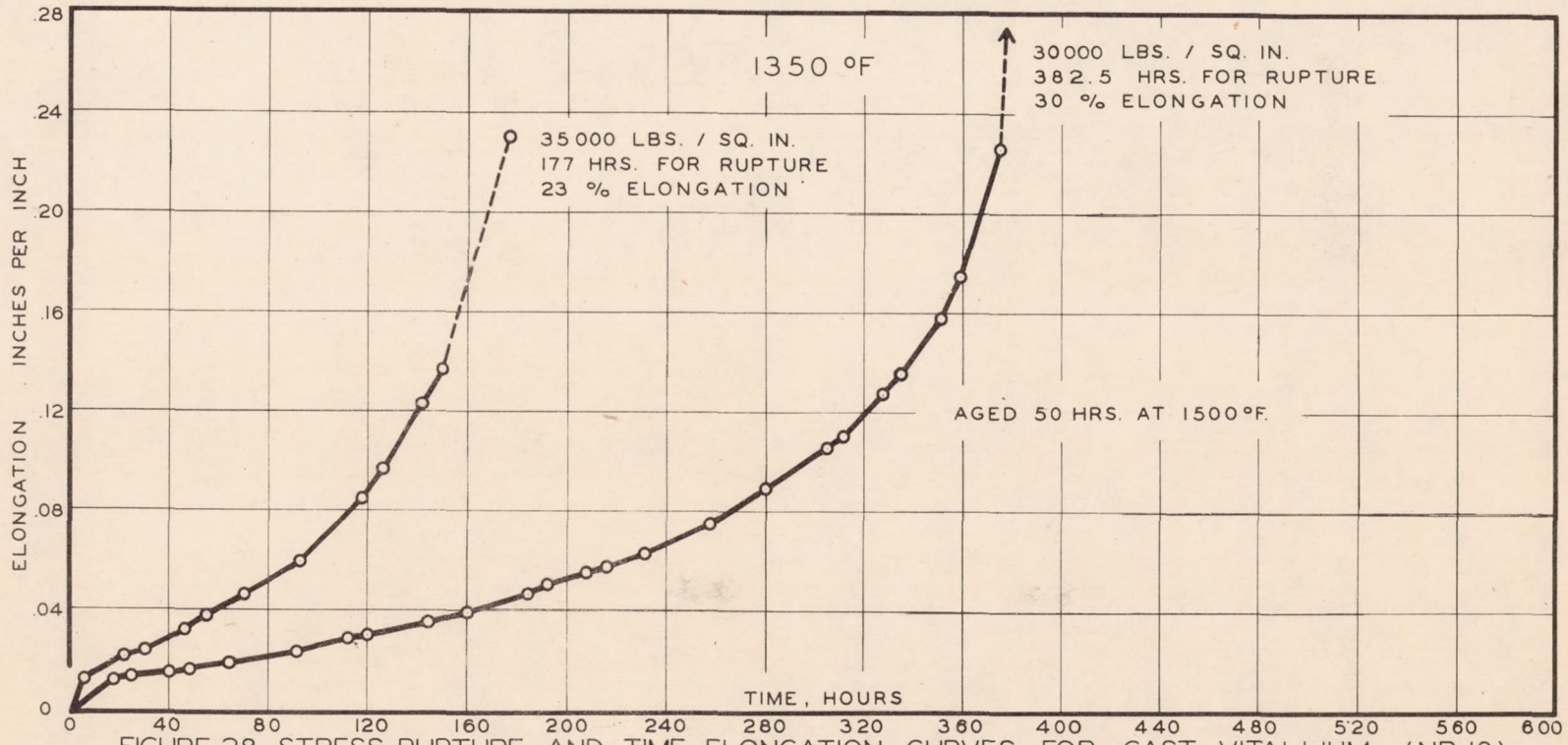


FIGURE 28- STRESS-RUPTURE AND TIME-ELONGATION CURVES FOR CAST VITALLIUM (NR 10)

ALLOY 422-19

MANUFACTURER Haynes-Stellite Company

COMPOSITION 0.40% C, 0.51% Si, 24.75% Cr, 15.92% Ni, 6.08% Mo, 0.65% Fe, Balance Co.

TREATMENT Cast by the Dental Investment Process as 1/4-inch diameter tensile test specimens with a one-inch gauge length. The specimens were cast complete with threads so that no machining was necessary.

The test bars were aged 50 hours at 1500°F. prior to testing.

The specimens were submitted by National Research Council Project 8 as their alloy designation NR-12.

HARDNESS 351 Vickers Brinell

STRESS-RUPTURE DATA AT 1350°F.

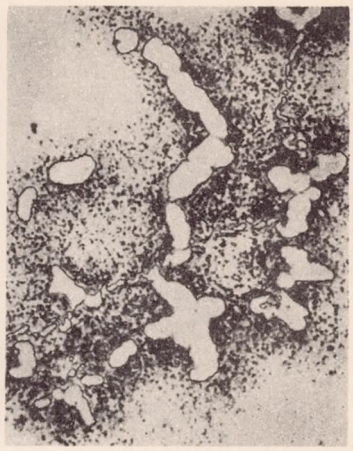
Stress Lb./Sq.In.	Time for Rupture Hours	Elongation % in 1 In.	Reduction of Area %
47,000	134.5	28.0	26.0
40,000	270.0	18.0	24.0
35,000	1452.5	10.0	21.4

STRESS-RUPTURE STRENGTHS AT 1350°F.
(from stress-rupture time plot)

Time for Rupture Hours	Stress Lb./Sq.In.
100	47,000
1000	36,000



100X



1000X

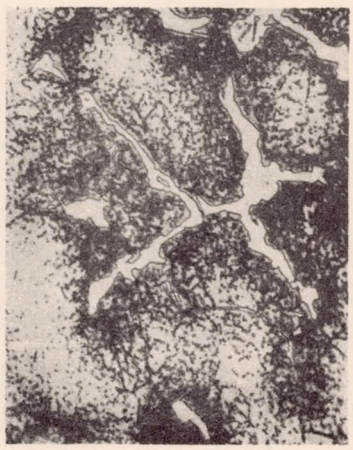
As Heat Treated

50 Hrs. at 1500°F.

Vickers Hardness - 351



Fracture - 100X



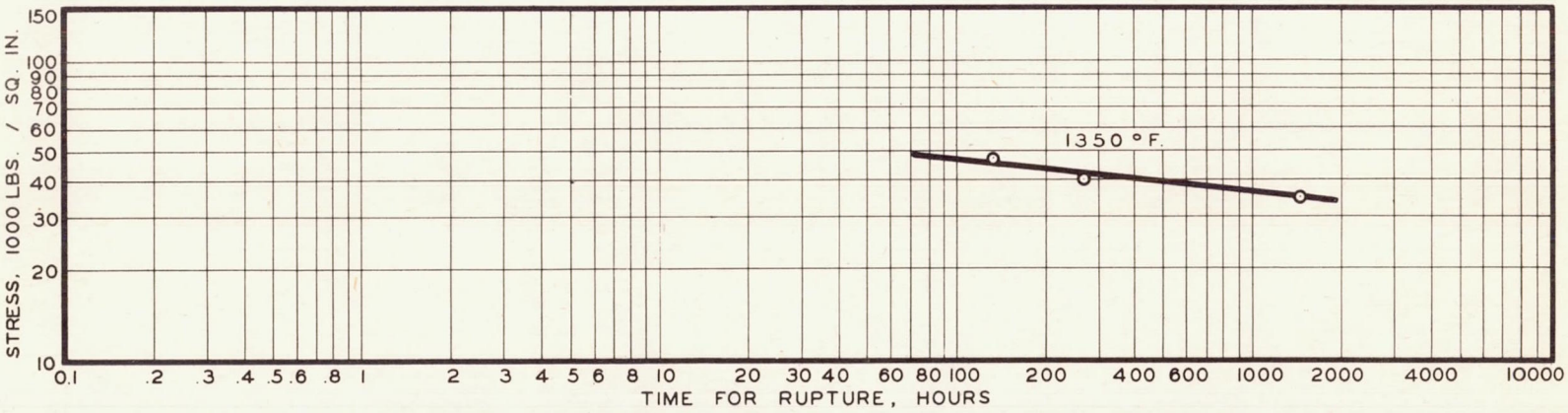
Interior - 1000X

1350°F.

35,000 Lbs. per Sq. In.
1452.5 Hrs. to Rupture

Vickers Hardness - 395

MICROSTRUCTURES OF ALLOY 422-19 (NR12) AFTER A RUPTURE TEST AT 1350°F.



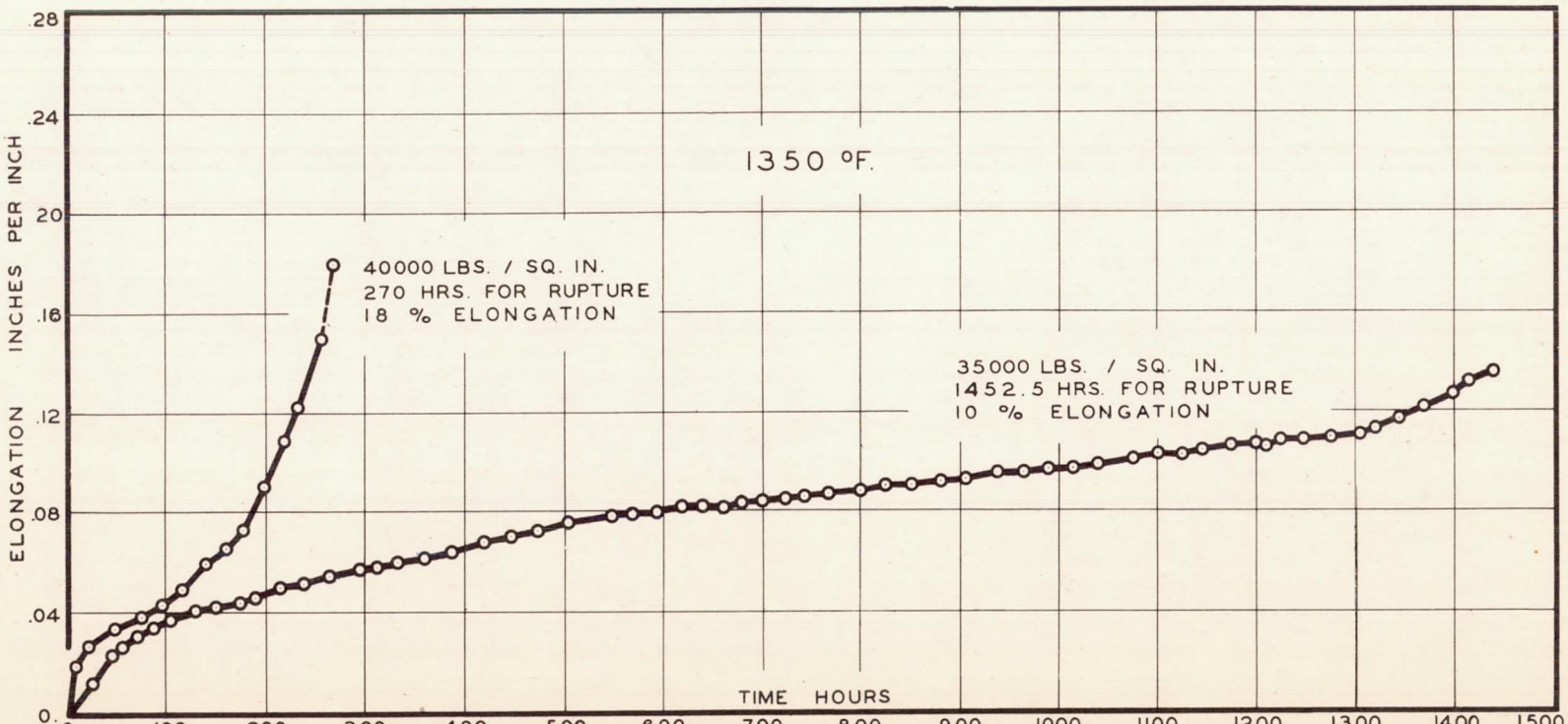


FIGURE 29- STRESS-RUPTURE AND TIME-ELONGATION CURVES FOR CAST 422-19 (NR 12)

ALLOY	61
MANUFACTURER	Haynes-Stellite Company
COMPOSITION	0.42% C, 24.07% Cr, 5.17% W, Balance Co.
TREATMENT	Cast by the Dental Investment Process as 1/4-inch diameter tensile test specimens with a one-inch gauge length. The specimens were cast complete with threads so that no machining was necessary. The test bars were aged 50 hours at 1500°F. prior to testing. The specimens were submitted by National Research Council Project 8 as their alloy designation NR-60.
HARDNESS	383 Vickers Brinell

STRESS-RUPTURE DATA AT 1350°F.

Stress Lb./Sq.In.	Time for Rupture Hours	Elongation % in 1 In.	Reduction of Area %
40,000	51.5	6.0	6.1
30,000	238.0	4.0	7.2
26,000	1550.5	5.0	7.9

STRESS-RUPTURE STRENGTHS AT 1350°F.
(from stress-rupture time plot)

Time for Rupture Hours	Stress Lb./Sq.In.
100	36,000
1000	27,000



100X



1000X

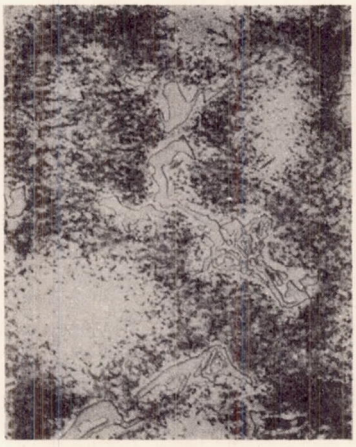
As Heat Treated

50 Hrs. at 1500°F.

Vickers Hardness - 383



Fracture - 100X



Interior - 1000X

1350°F.

26,000 Lbs. per Sq.In.
1550.5 Hrs. to Rupture

Vickers Hardness - 458

MICROSTRUCTURES OF CAST ALLOY 61 (NR60) AS HEAT TREATED
AND AFTER A RUPTURE TEST AT 1350°F.

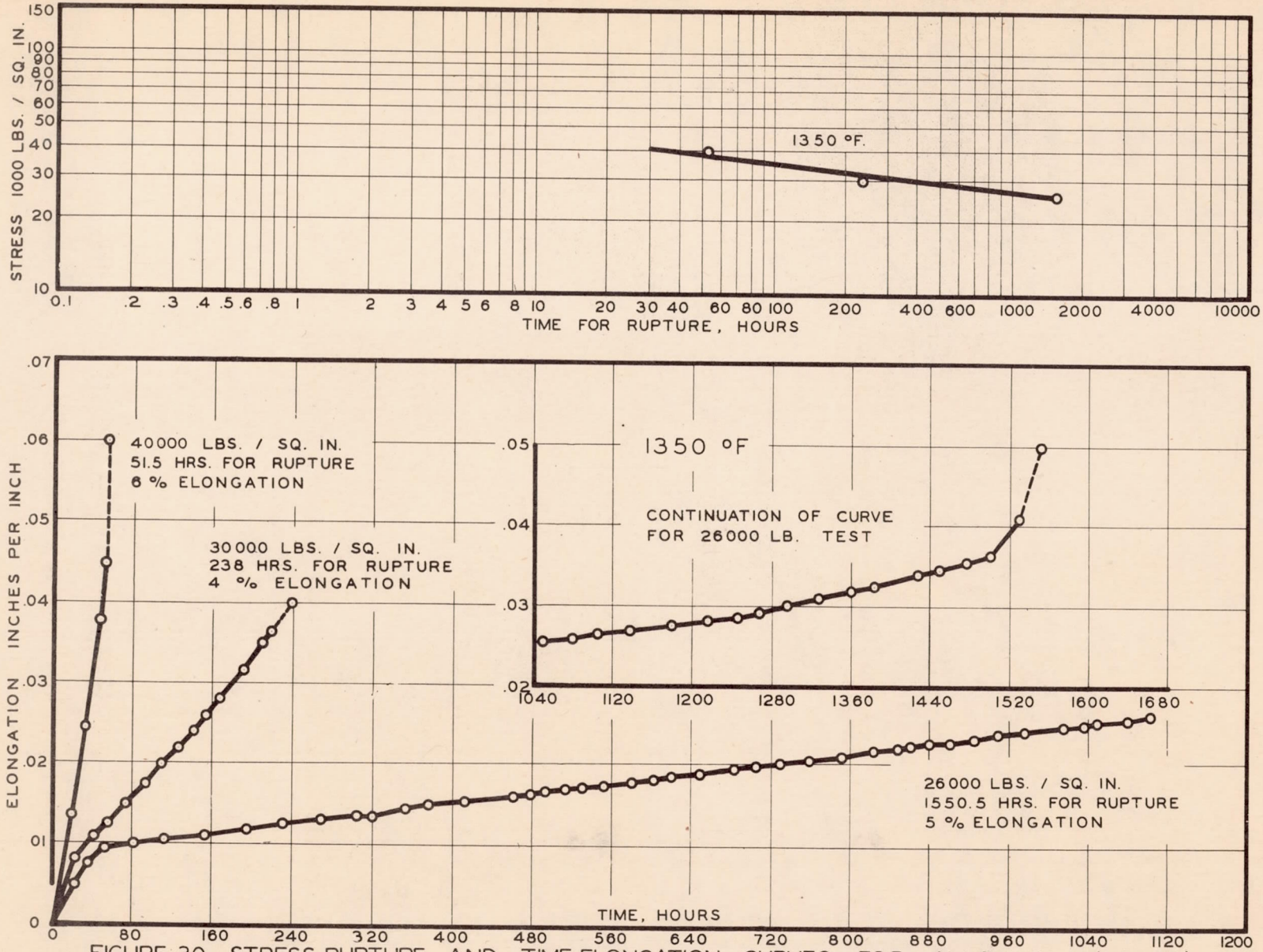


FIGURE 30 - STRESS-RUPTURE AND TIME-ELONGATION CURVES FOR ALLOY 61 (NR 60)

ALLOY 6059

MANUFACTURER Haynes-Stellite Company

COMPOSITION 0.46% C, 26.17% Cr, 6.4% Mo, 1/2 Balance Ni, 1/2 Balance Co.

TREATMENT Cast by the Dental Investment Process as 1/4-inch diameter tensile test specimens with a one-inch gauge length. The specimens were cast complete with threads so that no machining was necessary.

The test bars were aged 50 hours at 1500°F. prior to testing.

The specimens were submitted by National Research Council Project 8 as their alloy designation NR-63.

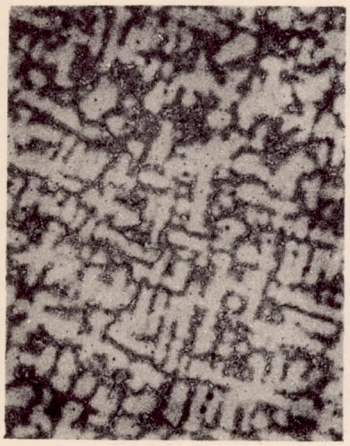
HARDNESS 300 Vickers Brinell

STRESS-RUPTURE DATA AT 1350°F.

Stress Lb./Sq.In.	Time for Rupture Hours	Elongation % in 1 In.	Reduction of Area %
40,000	23.5	17.0	27.7
38,000	75.0	18.0	40.0
35,000	436.5	23.0	28.6
30,000	382.0	33.0	48.0

STRESS-RUPTURE STRENGTHS AT 1350°F.
(from stress-rupture time plot)

Time for Rupture Hours	Stress Lb./Sq.In.
100	36,500
1000	30,500



100X

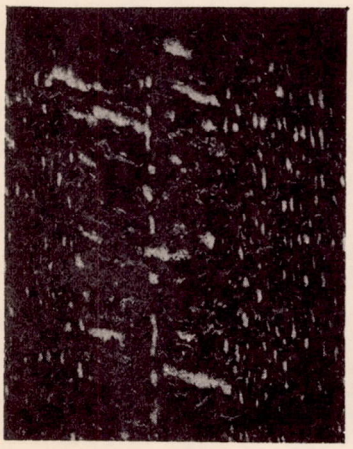


1000X

As Heat Treated

50 Hrs. at 1500°F.

Vickers Hardness - 300



Fracture - 100X



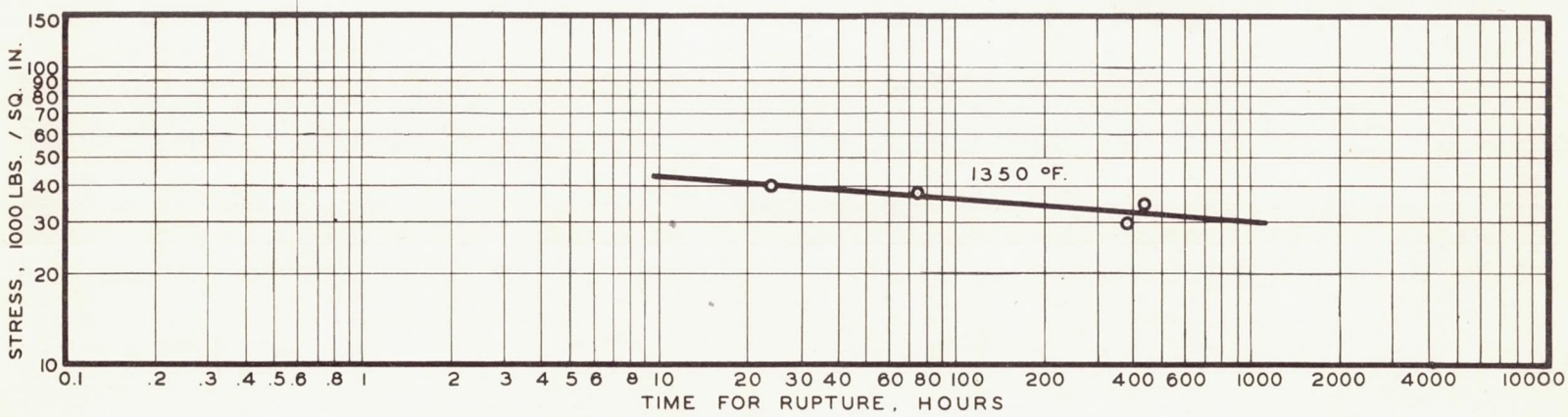
Interior - 1000X

1350°F.

30,000 Lbs. per Sq. In.
382.0 Hrs. to Rupture

Vickers Hardness - 338

MICROSTRUCTURES OF CAST ALLOY 6059 (NR63) AS HEAT TREATED
AND AFTER A RUPTURE TEST AT 1350°F.



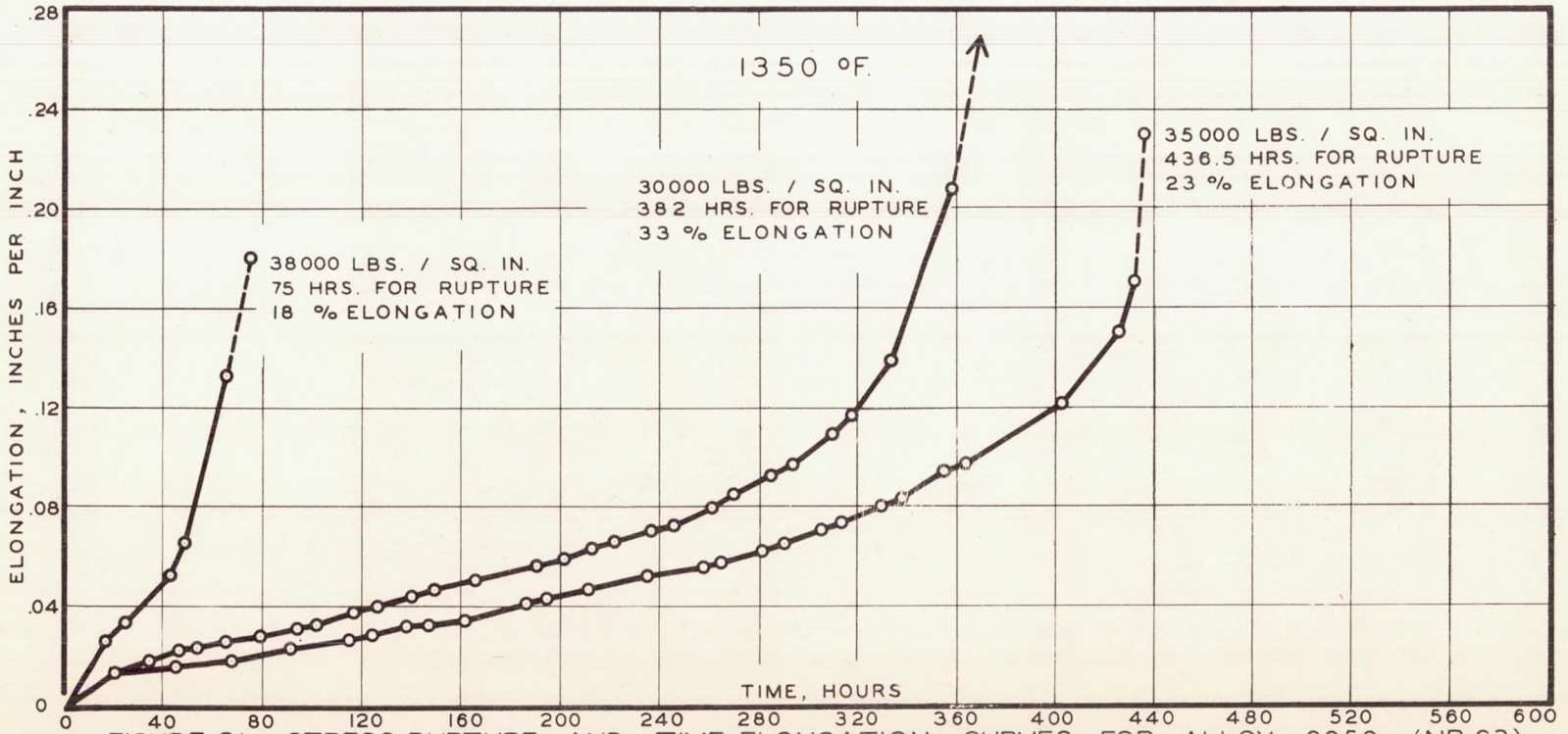


FIGURE 31- STRESS-RUPTURE AND TIME-ELONGATION CURVES FOR ALLOY 6059 (NR 63)